UNCLASSIFIED

| AD NUMBER |
|---|
| ADC054990 |
| CLASSIFICATION CHANGES |
| TO: unclassified |
| FROM: secret |
| LIMITATION CHANGES |
| TO: Approved for public release, distribution unlimited |
| FROM: Controlling DoD Organization...Office of Naval Research Laboratory, Washington, DC. |
| AUTHORITY |
| NRL Code 300 ltr, 23 Feb 1996; NRL Code 300 ltr, 23 Feb 1996 |

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# NAVAL RESEARCH LABORATORY REPORT

24 October 1941

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Report No. R-1794

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NAVY DEPARTMENT
OFFICE OF NAVAL RESEARCH
NAVAL RESEARCH LABORATORY
WASHINGTON 20, D. C.

24 October 1941

NRL Report No. R-1794
BuShips Problem X7-2S

NAVY DEPARTMENT

**Report on**

**Ship to Ship Pulse Recognition System (S)**

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

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| Number of Pages: | Text - 52 Tables - 6 Plates - 52 |
| Authorization: | BuEng secret letr. S-S67(1-24-R) Serial No. 321 of March 2, 1939. |
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| Distribution: | BuShips (2)<br>OpNav(INC) (1) |

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SERIAL No. 4 of 4

ABSTRACT

A completely automatic ship to ship recognition system utilizing ultra-high frequencies is described. A very short signal (on the order of a millisecond long) consisting of a group of pulses, constitute the challenging and replying signals. A total of 4100 different codings is provided with the reply coded independently of the challenge. An optical reply system is included to corroborate or replace the radio reply at the will of the challenging operator. The automatic operation as well as the coding is obtained almost completely through the use of electronic circuits employing vacuum tube switches and counters. The results of tests conducted on the complete system over a land distance of eight miles are discussed.

TABLE OF CONTENTS

TABLE OF CONTENTS

(continued)

## TABLE OF CONTENTS

List of Tables

## TABLE OF CONTENTS

### List of Plates

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## I. AUTHORIZATION

### A. References

(a) - Bureau of Engineering secret letter S-S67 (7-29-R)
Serial No. 237 of August 1, 1938.

(b) - Bureau of Engineering secret letter S-S70 (3-16-R)
Serial No. 249 of August 17, 1938.

(c) - Naval Research Laboratory secret letter S-S67/33
Serial No. 111 of January 17, 1939.

(d) - Bureau of Engineering secret letter S-S67 (1-24-R)
Serial No. 321 of March 2, 1939.

The establishment of the general problem of pulse transmission and reception is given in reference (a) as Bureau of Engineering Problem X4-13.

The establishment of the specific problem of pulse transmission and reception applied to ship to ship recognition is given in reference (b) as Bureau of Engineering Problem X7-2S.

A preliminary report on the ship to ship recognition system is given in reference (c).

The authorization for a two pulse group, two counter relay operated recognition system is given in reference (d). This reference also calls for a two group, four counter system to be held in reserve in case of an emergency.

The system herein described is a one group electronic system using one carrier frequency. The latter is an outgrowth of the system called for in the authorization and is considered far superior to the relay system. The development of the one system from the other and the reasons for the changes made are discussed in detail under Section VI.

## II. STATEMENT OF PROBLEM

The function of a recognition system is simply that of providing a means whereby any ship, plane, submarine, ground station, or the like can reliably determine whether any other ship, plane, submarine, ground station or the like is that of a friend or an enemy. Furthermore, it must do so without betraying itself to the enemy.

Recognition can of course be simply reduced to that of visual identification (by silhouette, etc.) in which case any recognition system (optical, radio, etc.) would merely act as a check on the visual. However, in the general case the visual method cannot be relied upon, as for example in the case of fog or at night, and some other, more reliable system becomes necessary.

The method proposed herein is one utilising signals at radio frequencies or, more specifically, at the ultra-high radio frequencies of 400 to 500 megacycles per second.

Since this problem was originally for purposes of ship to ship recognition, it will hereafter be assumed that the recognition problem is between two ships. It is not at all confined to this, although in its present shape its weight would not lend itself to general aircraft use.

The problem then is that a ship, having by some means or other ascertained the presence of another ship within a twenty-mile radius of it, desires to determine the identity of the other (i.e., as to whether it is friend or enemy. The problem of specifically identifying the individual ship if it is a friend, is an extension of the method described here, development of which is at present continuing). To do so it is necessary for the former to send out a signal which shall hereafter be called the challenge. It is then necessary for the other ship (to be called the challenged or replying ship), if it is a friend, to intercept that challenge and transmit back to the challenging ship a proper reply. If the challenged ship is an enemy, the challenge will go unanswered or be answered incorrectly. This procedure is involved in any type of recognition system.

Before going into a description of the proposed system, consider first the requirement of an ideal recognition system so as to obtain some idea of the scope of the problem.

It may be said parenthetically that the Navy would do well to have a visual recognition system as a standby method for employment during such times when, because of unpredictable conditions, the primary radio system has been made inoperative by accident, shell fire, shock, etc.

An ideal recognition system should embrace the following characteristics:

(1) It must be extremely reliable.
(2) It must be as near interference-proof as possible.

(3) The signals used must be of such a character to make detection by the enemy extremely difficult.
(4) The operation should be completely automatic.
(5) The size and weight should be as small as possible.

To attain all of these characteristics in a single system is of course very difficult if not impossible. For example, anything that is done to make a system interference-proof is likely to add to its complexity and so decrease its reliability and increase its size. A certain amount of compromise becomes necessary. In the system herein described, the various items have been carefully weighed and as near an approach as possible to the ideal system has been made.

1. Reliability

The recognition method that is proposed is based primarily on electronic circuits, the number of mechanical operations (relays, switches, etc.) having been reduced to a minimum. It was felt that this would considerably increase the reliability. Since a certain number of electronic circuits are necessary, there is always the danger of interaction between the mechanical and electronic operations. This is especially true of the system under consideration and will be taken up at a later point. The mechanical operations are restricted to some period before and some period after the complete electronic cycle. The reliability then is dependent on the stability of the electronic circuits, the life of the electronic tubes and the reliability of two mechanical relays. Actual reliability data as found under test are given in Section VII.

2. Interference

To make a system interference-proof two things are necessary. First, it must be jam-proof (i.e., not susceptible to complete blocking of the unit, as for example with a cw signal), and second, it must be impossible to "break down" the system and effect its correct operation. The method under consideration relies principally on pulse transmission with its high peak powers, and consequent low receiver sensitivity, to realize a not-too-easily jammed system. Furthermore, the high frequencies which are used (between 400 and 500 megacycles) limit the interfering source to the line of sight. Such an interfering source would not be very likely to exist because it would have considerable tendency to betray its position for purposes of interference.

The second type of interference referred to above is very difficult to accomplish under the proposed system. The methods available for making a system difficult to break down are (a) code the signal so as to make as few repeats as possible; (b) use a type of signal which is difficult to record; and (c) use type of signal which is difficult to reproduce. All three of these methods are used. The final model described in this report has a total of approximately 4100 different codes; the challenging signal is coded independently of the reply; from 50 to 3000 microseconds are required

to send out any one of the 4100 possible signals. An optical reply system is included to supplement the radio reply when so desired.

Thus, were an enemy to try and break down the system and have himself recognized as a friend he would have to know and do as follows:

(a) determine the carrier frequency and have a receiver and transmitter operating on this frequency. (The transmitter would have to have sufficient peak power to operate a relatively insensitive receiver);
(b) determine the exact time (within a millisecond or so) of the arrival of a challenging signal and be prepared to send an answer within several milliseconds;
(c) know the answering code in use at that particular time;
(d) know the type of signal being used;
(e) have some knowledge of the correct modulation frequency to use. (In the present equipment no attempt is made to especially restrict the modulation frequency although this presents an additional means of coding the system. Nevertheless, for proper operation the modulation frequency must be within ± 50% of its correct value);
(f) be prepared to send an optical reply under certain coded conditions.

To accomplish all of these things it would be necessary for the enemy to have a complete duplicate set of the equipment being used by the challenger. The complexity of this equipment would forestall any rapid acquisition of it by the enemy even after all of the facts outlined above are ferreted out.

3. Detectability

A good recognition signal should be undetectable by anyone except the ship at which it is aimed, so as not to give away the challenging ship's position. A signal which cannot be detected by the enemy is, of course, impossible to attain. However, the ease with which it can be detected depends on

(a) length of time signal is on;
(b) signal intensity;
(c) signal range.

As was pointed out above, in the proposed system the signal is on from 50 to 3000 microseconds for the challenge and an equal time for the answer, the time between the arrival of a challenge and the transmission of an answer not exceeding another 50 microseconds. The net result is that, should anyone by some remote chance be standing by on the correct frequency (the probability of this frequency being located by sweeping or any other similar means is exceedingly small since a six millisecond signal which is on but once or twice a day or even several times in an hour is not very

easily located) the signal would sound very similar to a crash of static, that is as a single click, there being sufficiently short time between challenge and answer to make it sound as one click. Furthermore, the use of very short pulse widths would demand that the reception be made on a broad-band receiver.

The signal intensity is of course very high within the signal range. However, at the frequencies used, the signal range is limited very nearly to the line of sight. This limits any interception of the signal to approximately 30 miles by ship or about 100 to 200 miles by air.

All of these factors add together to give a recognition signal which approaches very near to the ideal case of complete radio silence.

4. Automatic operation

By automatic operation is meant that after a challenging signal has been initiated, its reception and the transmission of the correct reply are automatically accomplished without the attendance of an operator at the replying point. This is exactly what is done in the present scheme. To initiate a challenge it is merely necessary to direct an antenna and depress a switch. The challenged unit will automatically send back the correct answer, the reception of which will be indicated by the lighting of a lamp at the challenging unit. It is, of course, necessary for operators at both ends to set up the correct codes at such times as previously agreed upon.

5. Size and weight

The size and weight of this unit have been kept to a minimum in so far as possible. The use of an insensitive receiver to give greater reliability demands a more powerful and hence larger transmitter. Automatic operation as well as complex coding also add considerably to the size. The complete unit not counting the antenna has a volume of approximately ten cubic feet and weighs about 300 pounds. Certain possible changes brought out in the construction of the present unit could be applied, without changing the basic operation, to effect a decrease in weight of perhaps ten per cent.

## III. GENERAL OPERATION

### A. The Challenge

It was pointed out previously that the recognition system consists of a very short coded signal sent out as a challenge and a similar differently coded signal sent back as an answer. Actually this signal consists of almost rectangular pulses having a width of about 3 microseconds (u sec.) with a pulse spacing of 50 u sec. These pulses are obtained by the use of "scale of two" electronic counters employing vacuum tubes. The use of six such counter stages enables the accurate counting off of the cycles of oscillation of a 20 Kc oscillator. By means of electronic switches the oscillator is switched on, and after the counter has counted off the proper number of cycles the oscillator is switched off. The manipulation of six switches before a challenge is made allows the selection of any number of pulses up to and including sixty-four. These six switches merely set the six counter stages up to react to a given count. The limit of sixty-four is a result of the fact that the "scale of two" counters go through a complete cycle of operation for every two pulses they receive. With six stages in cascade, the complete cycle will involve $2^6$ or 64 pulses. The addition of more stages will obviously increase the coding possibilities.

The oscillator output (a group of pulses) is used to key a 430 Mc transmitter which consists merely of an oscillator, grid keyed on and off. Since only a maximum of sixty-four pulses of 8 microseconds each are to be transmitted at most once every second, the total time the transmitter is on during a second is very small. Thus for the maximum conditions of one transmission per second this corresponds to a duty cycle of .00051 (by duty cycle is meant the fraction of time the transmitter is on in unit time). The transmitter has a peak power output of almost one kilowatt but due to the low duty cycle this means a very low average power. Consequently it is possible to use a very small high voltage power supply continually charging a condenser for the plate supply of the oscillator. The power for any group of pulses is drawn from the condenser which then has a relatively long time during which to recharge. The size of the condenser is made large enough so that the total voltage drop across it for the maximum group to be sent is less than 5%. This eliminates the possibility of any serious frequency modulation of the oscillator during a transmission. The great advantage of pulse transmission is here aptly illustrated by the small power requirements on both the oscillator tubes and the power supply.

The signal is radiated on a Yagi type directional antenna whose beam width at half energy is 45°. It is assumed that this Yagi antenna is to be mounted on the bridge or a similar elevated position (if mounted on the bridge it will probably be necessary to use two antennas each sweeping 180°). The unit proper can be placed below ship or at any convenient spot. The operator directs the antenna at the ship in question and by pressing a key in a remote control box at the antenna, initiates the challenge.

Depression of the key also throws an antenna switch which changes the unit from a non-directional antenna for stand-by to a directive antenna for the challenge. The operator is assured that the signal has gone out by a light (hereafter called the amber light) going out in the remote control box. This light serves the further purpose of indicating the existence of any interference being picked up by the receiver. Since the receiver is rather insensitive, the interference will only be occasional, due to such things as severe static crashes or severe local disturbances. In this case the amber light serves the important purpose of preventing a friend from appearing as an enemy, due to interference. Hence in making a challenge it is important that it be done only when the amber light is on.

B. Reception of challenge and reply

The signal is picked up by the challenged ship on a non-directional antenna. An analysis of the signal is made electronically to determine if it is of the correct count, as previously agreed upon. The circuits will reject any signal if it is not of the exact count for which they are set up. This means that no reply is sent to the challenge. However, if the received signal is correct, the transmitter is triggered off and a reply sent out on a non-directional antenna within 50 micro-seconds of the time the original signal was received. Only one antenna is used for this reception and transmission, the common use being accomplished with the aid of resonant concentric lines and a gas tube (called a "duplexer") placed in the transmission lines between receiver, transmitter and antenna.

The transmission of a reply is identical to the transmission of a challenge with two exceptions. These are that a challenge is triggered off manually and transmitted on a directional antenna whereas the reply is automatically tripped off and transmitted on a non-directional antenna. The coding of the challenge is independent of the coding of the reply.

If the correct signal has been received and a reply sent out, a green light will go on in the remote control box of the reply unit. It is thus possible for the challenged ship to detect a challenge if a constant watch is maintained. It would be a very simple addition, if so desired, to have the challenge ring a bell or the like on the challenged ship to indicate the presence of a friend.

After the reception of a signal, the reply unit is blocked for an arbitrary period (at present set at one second) after which it clears itself into a standby position. The reason for this delay will become apparent under the discussion of "reception of reply".

C. Reception of reply

Assuming that the correct challenge has gone out, been received and a reply sent out, the challenger should receive the reply no more than

300 microseconds later (assuming a maximum range of 20 miles) than transmission of the challenge. This means that the switch which was originally closed to send the challenge is still closed, as a result of which the reply is received on the same antenna on which the challenge was transmitted, namely, the directional one. It is one of the requirements of the system that the challenging switch be held down for at least 0.1 second but not more than about one second (violation of the latter is not serious, it would merely result in two or more transmissions). The maximum time of one second is arbitrary and can be set for any desired value. The minimum time of 0.1 second is fixed by the operating time of the antenna switch. In operating a challenge switch manually it is, of course, difficult to close and open it in such a way that the closed time is less than the minimum here prescribed.

The incoming reply is analyzed electronically in the challenging unit in a manner very similar to that of the incoming challenge in the reply unit. If the signal is analyzed as correct, a green light is lit in the remote control box. This green light is kept lit for a period just long enough to definitely identify it. At present this time is approximately one second. The reason this time is kept short is because the entire system is blocked to an incoming challenge from other ships during this period. As pointed out above, the reply unit is blocked for a similar period. After this period is up both units revert to a standby position on the non-directional antennas.

Recognition has now been accomplished in something like one quarter of a second with the units being inoperative (as far as any other recognition signals are concerned) for a period of one second.

D. Optical reply

The present carrier frequency and antenna size result in an antenna directivity which is broad enough to include several ships within its beam if they are close enough together. If one of the ships is a friend, it would be impossible by means of the radio reply to determine which was the friend. If several or all of the ships are friends, several answers would come back with phase differences between them. The challenging unit would probably analyze this as an error. This would result in several friends being recognized as enemies. The system could be used however on much higher carrier frequencies, with higher directivity.

To take care of these contingencies, an optical reply system has been included to corroborate, if desired, the radio reply. It consists merely of a blinker placed on the mast which can be lit by the challenging ship. The challenge is made in the normal manner described above. If there is any doubt about the reply, the challenge is repeated two more times (for a total of three times). If a friendly ship receives three correct signals and transmits three replies, its blinker light will flash on. The duration of this flash is controllable, at present being set at about 1/4 second. The three challenges must be completed within a definite time (at

present set at 12 seconds) after which the blinker system returns to its original position and three or more signals are required to light it.

This system obviously does not have the shortcomings of the old two way optical recognition system. If an enemy did try to give the optical reply, he would have to respond

1) only after three challenges within the blinker cycle time,
2) within one tenth of a second after the reception of the last challenge,
3) with a blinker flash of the proper duration.

E. Operating instructions

On the basis of the above discussion and assuming that the unit is in operating condition, the method of operation is as follows: (all operations are conducted on the antenna and remote control box)

(1) Check that the unit is on by noting whether the red pilot light is on. If the unit has just been turned on or if some change in the coding has been made, it is necessary to manually "clear" the counters and switches. This is done by snapping the challenge switch up.
(2) Direct the antenna toward the ship being challenged.
(3) If the amber light is on press the switch all the way down until the amber light goes out. Then release the switch.
(4) Watch the green light. It should come on within one-tenth of a second after the switch has been depressed and stay on for approximately one second, after which it goes out and the amber comes back on. If the green light does not come on there is no recognition.
(5) To get an optical reply, repeat the above a total of three times within twelve seconds and watch for the blinker flash.

IV. DESCRIPTION OF EQUIPMENT

A. General

The complete recognition unit consists of the following:

1. The cabinet containing the transmitter, receiver, keyer-recogniser and a motor driven blower.
2. The remote control box and the control cable to the cabinet.
3. The blinker light and its cable.
4. The propagation system including the directional antenna, non-directional antenna, antenna switch and duplexer.

A block diagram of the recognition unit is shown on plate 1.

A list of general specifications is given in Table 1.

The recognition unit uses 62 standard type electronic tubes and a helium filled gas tube in the duplexer. The standard type tubes are listed in Table 2. The location in the unit of the various tubes is indicated on the following plates; Plate 105 - Top View of Transmitter, Plate 107 - Top View of Receiver, Plate 22 - Keyer-recogniser front view showing location of stages, and Plate 25 - Top View of Keyer-recogniser power supply.

1. Cabinet

The steel cabinet contains three shelves, the upper two of which have built-in aluminum shield cans. The top shelf houses the transmitter; the middle, the keyer-recogniser and receiver, the receiver being mounted at the rear of the keyer-recogniser chassis above the keyer-recogniser power supply. The bottom shelf houses the blower and motor, a variac, a voltmeter and a switch in the a-c supply circuit.

The ventilating system employs a blower driven by a 0.1 h.p. motor. Air enters at the bottom of the cabinet, passes through a glass filter into the blower housing, and goes through the upper shelves leaving through holes near the top of the cabinet. The shield cans are perforated to allow free passage of the ventilating stream.

The upper front panel of the cabinet mounts a pilot light from the a-c supply to the unit, a toggle switch, pilot light and variac (GR200C) in the a-c supply to the high voltage transformer in the transmitter. The middle panel has a small door opening downward to give ready access to the coding switches. The lower panel mounts a variac (GR200C), voltmeter (0-150 volts) and switch in the a-c supply to the unit. (See Plate 101)

At the rear panel are the keying line with plug connections to the keyer-recognizer and transmitter, the 9 wire control cable with plug connection to the keyer-recognizer (see Plate 102), plug connections from the transmitter and receiver to the duplexer, the receiver gain control knob and dial, and the receiver tuning knob and dial. Two holes near the gain control give access to phono tip jacks connected to the receiver output. The transmitter plunger extends beyond the panel. Two holes below the plunger expose the oscillator filament frame adjusting screws in the transmitter.

A hole in the left side of the cabinet gives access to the receiver preselector, which may be tuned with a long shank screwdriver. At the top of the cabinet are a plug connection from the duplexer to the antenna switch, the control leads to the antenna switch, a 2-prong plug connection to the blinker light, and a 9-prong plug connection to the control cable.

The a-c power plug is located on the left side of the cabinet near the lower rear corner. The unit operates directly from the 115 volt a-c line, has a power consumption of 675 watts, and will operate satisfactorily over an AC voltage range of 110-120 volts.

The transmitter, receiver and keyer-recognizer are described on the succeeding pages.

2. Remote Control Box and Cable

The remote control box contains (1) the keying switch which when depressed, initiates the challenge and trips the antenna switch to the directional antenna, and when raised, clears the keyer-recognizer to its initial state (it should be necessary to clear only after the unit has been turned on or after the coding switches have been changed), (2) the pilot light (red) which indicates when the 115 volt a-c power switch is on, (3) the challenge light (amber) which is normally on and goes out on the transmission or reception of a challenge or on reception of interference, (4) the recognition light (green) which is normally out and goes on after the transmission or reception of a correct reply indicating recognition, and (5) the 9-prong plug which connects with the 9-wire control cable from the top of the cabinet. The indicator lights are 6 watt, 115 volt lamps. The wiring of the control box and control leads are shown on Plate 2.

3. Blinker Light and Cable

The blinker light is energized from the 115 volt a-c line and controlled from the keyer-recognizer through a two wire cable. The blinker light uses three 15 watt, 115 volt lamps in parallel.

4. Propagation System

The propagation system (antennas, antenna switch and duplexer) is described on succeeding pages.

B. Transmitter

1. General Information

The ultra-high frequency transmitter operates at 428.5 megacycles and has a pulse peak output of approximately 0.9 kilowatt.

The high voltage power supply charges a 2 microfarad condenser to 6500 volts. When keyed for the maximum signal of 64 pulses, the condenser discharges 160 volts, at a peak rate of 0.67 amperes, the peak power input to the oscillator being 4.33 kilowatts. Since the oscillator efficiency is approximately 20%, this gives an output of 0.866 kilowatts. It requires 275 watts at 110 volts, 60 cycles, to power the transmitter. The keying pulse frequency is 20.8 kilocycles and the average pulse width 7.5 microseconds.

A circuit diagram of the transmitter is shown on Plate 3.

2. Oscillator

The oscillator uses four HK24 gammatrons operating at a plate voltage of 6500 volts. An RCA high voltage power transformer #9861 rated at 7500 volts and 2 milliamperes operating from the 115 volt a-c line through a variac (GR200B) supplies plate voltage to the 879 rectifier for half wave rectification. The same transformer supplies the 879 filament. A 5 megohm bleeder across the high voltage system gives better regulation and protection. A pilot light and toggle switch on the front panel are in the a-c line to the H.V. transformer. The oscillator filaments are supplied from two 110/6.3 volt 6 ampere transformers, each secondary feeding two tube filaments through a tuning frame. The frames are adjusted by shafts having a total rotation of 78 turns and may be reached through holes in the rear panel of the cabinet. The filaments are biased to -100 volts at the secondary center taps and are bi-passed to ground through a .006 microfarad 5000 volt condenser. Through this means, a lower grid bias is reached, since the maximum positive grid swing is -120 volts. The size of the .006 mfd condenser is somewhat critical and is chosen for maximum signal output within the limits of correct transmitted pulse count. Too large a condenser will result in a reduced pulse count being transmitted.

The output coil is a single turn, one end of which feeds the antenna system. The other end is grounded in a tuning plunger the length of which can be varied and which serves to match the oscillator to the antenna system. The plunger tube passes through the shield can and extends beyond the rear of the cabinet. The plunger is advanced or retracted by means of a rod inserted at the far end.

The oscillator grids are biased from the plate of the 807.

3. Keying circuit

The keying circuit is an 807 beam power tetrode operating below ground potential. The plate resistor of the keying tube (5000 ohm 150 watt) serves also as the oscillator grid leak. Thus the plate voltage on the 807 is the bias voltage on the oscillator. With the 807 cathode at -600 volts and the grid at zero bias, the plate (and hence oscillator grid) is at -520 volts. This is sufficient to bias off the oscillator. The 807 screen is at +380 volts with respect to the cathode.

A negative pulse of 75 volts on the keying tube grid causes its plate to rise to -120 volts, (since the oscillator cathode has a bias of -100 volts, the net oscillator bias is very near zero) unbiasing the oscillator during the period of the pulse. The pulse wave form on the 807 plate is shown on Plate 4 in which zero volts corresponds to the minimum plate voltage -520 volts.

The 807 power supply is of the conventional type delivering 150 milliamperes at 600 volts.

C. Receiver

1. General Information

The ultra-high frequency receiver employs a superheterodyne circuit and use the following eight tubes: an r-f oscillator (955), an r-f detector (954), three i-f amplifiers (6AC7), a second detector (6AC7), an a-f amplifier (6SJ7), and a full wave rectifier (5Z4).

The receiver has a radio frequency range of from 410 to 450 megacycles; the standard operating frequency is 428.5 megacycles.

The intermediate frequency is 46 megacycles and the average i-f band width 0.6 mc. At full gain the output of the 2nd detector is 3 volts for an input to the first detector of 100 microvolts. This corresponds to a maximum overall i.f. gain of 30,000. The receiver sensitivity is purposely kept low to reduce the possibility of interference. A circuit diagram of the receiver is shown in Plate 5.

2. Component Parts

a. Oscillator

The oscillator is a 955 acorn triode with grid to plate coupling through 25 micromicrofarads in series with a variable resonant two wire line (tuning frame). The shorting bar of the frame is moved by a screw to vary the frequency. The total range on the screw is 48 turns, each turn shifting the frequency 0.9 megacycles. The frequency range is then 43 Mc corresponding to a carrier frequency range of approximately 410 to 450 Mc.

b. First Detector

The signal from the antenna is fed into a "high Q", tuned quarter-wave concentric tank shorted at one end. This preselector functions to increase the r.f. selectivity of the receiver and to reduce the effect of ultra-high frequency interference. It consists of a cylindrical tank 18.5 cms. long and 4.8 cms. in diameter with a concentric central conductor rigidly fixed to one end. Its length may be varied from 15 cm. to the total tank length by means of a screw driven extension. The input to the preselector is a 3/8" concentric line whose center conductor makes a small loop to ground which serves to inductively couple the antenna system to the preselector. The 1st detector control grid is similarly coupled.

The first detector is a 954 acorn pentode operated at a cathode bias of 7 volts. The suppressor is tied to cathode and both are by-passed to ground through 2.5 micromicrofarads. This low cathode bi-pass as well as an un-bipassed screen serve to increase the receiver sensitivity. The signal is impressed from the preselector (as noted above) to the 954 control

grid which is also coupled to the grid side of the oscillator tuning frame through a 70 micromicrofarad ceramic condenser.

c. Intermediate Frequency Circuit

The intermediate frequency circuit operates at a center frequency of 46 Mc with an average band width of 0.6 Mc for .7 center frequency voltage. The selectivity curve is given on Plate 6.

The I-F circuit consists of three stages of 6AC7's, the gain of two of which can be varied by varying their cathode bias. The gain control calibration is given on Plate 7.

The I.F. transformer consists of a tightly coupled primary and secondary wound on a polystyrene form. A brass core serves to tune the transformer and may be advanced or retracted by means of a screw through the top of the shield. Each primary is paralleled by a damping resistor to increase the band width. The present values of these resistors are all approximately 5000 Ω.

d. Second Detector

The second detector is a 6AC7 pentode operating at a cathode bias of 4.3 volts. The plate is coupled through 100 micromicrofarads to the grid of the a-f amplifier to block anything except signals having high frequency components. A lead from the plate is connected to a phone tip jack located on top of the chassis to the right of the gain control. This provides a convenient means of reaching the 2nd detector output for I.F. gain measurements. The second detector output is in the form of negative pulses.

e. Audio Frequency Amplifier

The A.F. amplifier is a 6SJ7 pentode operating at zero bias. The negative pulses from the second detector are amplified in the audio stage to give an output of positive pulses. The transmitter power and receiver sensitivity are such as to saturate the audio stage over the shorter ranges of the system (up to about 10 miles over sea water). This results in a receiver output of positive pulses whose amplitude varies from about 25 volts at the maximum distance to about 100 volts at the minimum distance.

The various receiver voltages are listed in Table 3.

3. Exterior Controls and Jacks

a. Oscillator Tuning Control

The oscillator tuning frame shaft is brought through the oscillator shield and the shield can at the rear panel of the cabinet on the right hand side. A fixed dial, engraved in degrees provides a means

of determining the relative positions of the knob. When the knob is rotated more than 360° the number of complete turns must be counted. The shaft makes a total of 43 turns. There is a backlash of about 60° which should always be taken up in a given direction. The approximate position of this knob for the operating frequency (423.5 Mc) is 20 turns counterclockwise after turning clockwise to the end of its travel.

b. Preselector Tuning Control

The length of the preselector center conductor is varied by means of a screw located in the oscillator shield. A long shank screwdriver inserted at a hole in the left hand side of the cabinet provides a means of turning the screw and tuning the preselector. This screw should first be turned clockwise until it stops and then brought to approximately 25 turns counterclockwise.

c. Gain Control

The shaft of the gain control resistor is brought through the receiver chassis and the shield can at the rear panel of the cabinet on the left hand side. A fixed dial, engraved in degrees provides a means of determining the position of the gain control. Gain readings are usually taken directly from this dial. The total angular displacement of the shaft is 300° corresponding to full gain. The gain control is for experimental purposes only. Any subsequent unit will have a fixed or semi-fixed gain.

d. Jacks

Two phone tip jacks are located to the left of the gain control and are reached through holes in the rear panel of the cabinet. Of these, the left hand jack is grounded. The right hand jack is connected to the receiver output.

A phone tip jack connected to the output of the 2nd detector is located on top of the chassis to the right of the gain control and is accessible when the receiver is removed from the cabinet.

A terminal strip with four jacks is located under the chassis at the right hand side. These engage four plugs on the keyer-recogniser chassis. Two of these plugs serve to supply 115 volts a.c. to the power transformer primary. They are located directly under the transformer. Of the other two, located under the choke, one is grounded, the other makes connection between the receiver output and the keyer-recogniser input.

## D. Keyer-recogniser

### 1. Functions of Keyer-recogniser

The keyer-recogniser has two states of operation; (1) on challenge, it sends out the challenging signal and receives the reply, and (2) on standby, it receives the challenging signal and sends out the reply.

The term "keyer-recogniser" was chosen because it embodies the major functions of the circuit it describes. A list of these functions follows:

(a) On challenge, it supplies the keying signal to the transmitter, and clears itself to receive the reply.
(b) On challenge, it recognises the received reply and clears finally.
(c) On standby, it recognises the received challenge and clears to transmit.
(d) On standby, it initiates transmission, provides the keying signal for the reply, and clears finally.
(e) It operates the indicator lights in the control box.
(f) It controls the blinker light.

### 2. Cycles of Operation

#### a. Cycle of Operation on Challenge

The operations on challenge of the various circuits in the keyer-recogniser are listed below in a time sequence starting with the control box as indicated in the block diagram of Plate 8.

(1) When the keying switch in the control box is depressed the keying circuit starts the multivibrator.

(2) The multivibrator simultaneously pulses the transmitter and the counter. The first pulse trips the amber light control and initiates the time delay period for final clearout.

(3) At the correct count, the multivibrator is stopped from the counter output through the keying circuit which also initiates intermediate clearout.

(4) Intermediate clearout resets the counter.

(5) The received reply is fed to the counter from the receiver amplifier. If an undercount is received the last counter stage is not tripped to deliver a negative pulse, the cycle is stopped until final clearout and the green light does not come on.

(6) If the count is correct the counter output trips the green light control and the green light comes on.

(7) If an overcount is received, the green light control is immediately reset and there is no visual indication on the green light.

(8) Final clearout (initiated in item 2) occurs after its time delay. The counter and switches are reset to their original state. The green light goes out, the amber light comes on and the cycle is completed.

b. Cycle of Operation on Standby

The operations on standby of the various circuits in the keyer-recognizer are listed below in a time sequence starting with the reception of a challenge as indicated in the block diagram of Plate 9.

(1) The received challenge is fed to the counter from the receiver amplifier. The first pulse trips the amber light control and initiates the time delay period for final clearout.

(2) If an undercount is received the last counter stage is not tripped to deliver a negative pulse and the cycle is stopped until final clearout.

(3) At the correct count, the counter output initiates intermediate clearout after a short time delay.

(4) If an overcount is received, intermediate clearout is blocked before it can operate and the cycle is stopped until final clearout.

(5) Intermediate clearout resets the counter and trips the keying circuit.

(6) The keying circuit starts the multivibrator.

(7) The multivibrator simultaneously pulses the transmitter and the counter.

(8) At the correct count, the multivibrator is stopped from the counter output through the keying circuit. The green light control is tripped from the counter output and the green light comes on.

(9) Final clearout (initiated in item 1) occurs after its time delay. The counter and switches are reset to their original state. The green light goes out, the amber light comes on and the cycle is completed.

c. Cycle of Operation of Blinker System

The operation of the various circuits in the blinker

system are shown in the block diagram of Plate 13 and are listed below in a time sequence starting with the reception of the first challenge. Three successive challenges within 12 seconds are required to operate the blinker.

(1) The blinker counter is pulsed in the standby cycle after the reception and recognition of a correct received signal. The keying circuit, which automatically initiates the reply, also serves to impress a single pulse on the blinker counter for each correct received count.

(2) On the first pulse, the blinker counter starts the slow time delay circuit which will operate the blinker clearout after 12 seconds if it has not been operated in the intervening time.

(3) On the third pulse, the blinker counter unblocks the blinker light control and the blinker light comes on. At the same moment the blinker counter starts the fast time delay circuit.

(4) After a brief time delay which corresponds to the time of the blinker light flash, the fast time delay circuit operates the blinker clearout.

(5) The clearout circuit resets the counter which now blocks the blinker light control and the light goes out. If less than 12 seconds have elapsed since the first received signal, the slow time delay circuit which has not operated is now blocked and the cycle is completed.

(6) On challenge the blinker clearout is tripped from the keying circuit. This clears the blinker system on each challenge and prevents its operation on the challenging unit.

3. <u>General Discussion of the Multivibrator, Electronic Switches and Counters.</u>

Since the principal components of the keyer-recogniser are the multivibrator, electronic switches, and counters, a general description of their operation will be given before launching into the complete circuit.

The counters and switches used in this system fall under the general classification of "scale-of-n" counters. By a scale-of-n counter is meant an aggregation of tubes and circuits operating on voltages such that the entire assembly has (n) and only (n) stable states. The simplest case is where n equals two. (The case of n = 1 is unimportant because it has only one stable state which makes it useless as either a switch or a counter). By cascading scale-of-two stages a scale-of-$2^m$ counter

can be made where n is the number of stages. By automatically presetting the state of each stage this can be made a scale-of-n counter. Greater detail on this will be given later.

a. Multivibrator

Because there is a very close relationship between the commonly used multivibrator and scale-of-two electronic counters or switches, consider first the simple triode multivibrator shown on Plate 11, Figure 1.

When the voltages are applied one of the tubes will have a plate current slightly greater than that of the other due to difference in tubes and circuit constants. Assume plate current of tube B to be the greater. The voltage at the point (b) will then begin to drop before that at (a). This results in a negative pulse being transferred through the condenser (C2) to the point (d) which increases the bias on A. If A has started to conduct, it will now as a result of the increased bias cause a rise in potential at (a). This is equivalent to a positive pulse which will be transferred through the condenser (C1) to (e), decreasing the bias on B, causing it to conduct more and produce a further drop of potential at (b). This process continues until the potential at (e) rises to zero (or slightly above) after which any increase in potential at (e) causes grid current to be drawn and the potential at (d) reaches the cut-off value for A.

After a time determined by the time constant $R_4C_2$ the negative charge on (d) leaks off through $R_4$, starting A to conduct, dropping the potential at (a) and hence at (e). Tube B then begins to cut off, increasing the potential at (b) and at (d) causing a further drop in potential at (a). This keeps up until (e) reaches cut-off and (d) reaches zero, at which point the process again reverses itself. The regenerative action during cut-off and cut-on results in a somewhat square wave-form on the plates of the tubes. If $R_1 = R_2$, $R_3 = R_4$ and $C_1 = C_2$, this wave form is symmetrical. If these constants are unequal an unsymmetrical wave form results. An oscillogram trace of the wave form on each plate of an unsymmetrical multivibrator used in the recognition system is shown on Plate 13, Figures 1 and 2.

b. Single Stage Triode Counter

The scale-of-two triode counter circuit differs from the multivibrator in that once a transition has been made (from B conducting to A conducting or vica versa), a stable state exists, necessitating an outside stimulus to return it to its original state. This is accomplished by two changes in the multivibrator circuit as shown on Plate 11, Figure 2, namely, the addition of the coupling resistances $R_5$ and $R_6$ and returning the grid resistors to a negative potential $E_c$. The two sets of resistances $R_4$, $R_2$, $R_6$ and $R_5$, $R_1$, $R_3$ are now bridged across $E_p$ and $E_c$. The resistance

and voltage values are so chosen that the steady state potential at (d) is beyond cut-off for A when B is conducting and the potential at (e) is zero when B is conducting. The latter need not be exactly true, for if the steady stage value at (e) is greater than zero, the flow of grid current will adjust it to zero. Normally this grid will run about 0.1 volt positive.

As shown above in the case of the multivibrator when the voltages are applied, one tube rises to a conducting state. Instead of reversing itself at this point as the multivibrator does, the counter remains in this initial state due to the bias developed across the resistance bridge. The grid which has been driven negative is held at a negative value, stabilizing the existing condition.

Suppose tube B is initially conducting and A non-conducting. If a negative pulse of amplitude equal or greater than the cut-off voltage is applied to the input point it will have no effect on A since it is already non-conducting. However, this pulse on the grid of B will stop it from conducting. The potential at (b) will now rise, sending a positive pulse to (d) and A will start conducting. The potential at (a) then falls, biasing off (e), further increasing the potential at (b) and so on, until a stable condition is arrived at, with A conducting and B non-conducting. A second negative pulse will return B to conducting and A to non-conducting.

It is, of course, necessary that the tripping pulse have a pulse width less than the time constant of the transfer circuit; otherwise both tubes will be held at cut-off until after the effect of the initial cut-off has died away. The net result will be that either tube may become conducting after the tripping pulse has been removed depending on the respective circuit and tube constants.

If a positive pulse is applied to the input point, a switch from one state to the other will again result. This is a decided disadvantage of the triode counter. The reason for this will be pointed out below.

c. Single Stage Multiple Grid Counter

The multiple grid tube has two advantages over the triode for use in counter circuits: (1) It can be made to respond to only negative pulses, (2) It can be reset more rapidly, more conveniently, and by more circuits.

A typical multiple grid counter circuit is shown on Plate 12. Ignore for the moment the resetting circuits and assume the cathodes and suppressors to be grounded. It will respond to negative pulses just as the triode did. The requirements on pulse width and amplitude of the tripping pulse are similar to those in the case of the triode. The amplitude must be equal or greater (preferably greater) than the cut-off voltage of the tube. The pulse width must be small with respect to the

transfer circuit time constant.

Figures 3, 4, and 5 of Plate 13 illustrate the operation of a multigridcounter stage receiving a series of negative pulses at a rate of 20 kilocycles (shown in Figure 2) from a multivibrator. Figure 3 shows the series of negative pulses on the grid of tube B. Figure 4 is an oscillogram of the voltage at (e) or grid #3 of B. As shown, B is originally conducting and (e) is at 0. The first pulse blocks B and (e) drops to cut-off. The second pulse blocks A; B again conducts and (e) returns to 0. Successive pulses merely repeat the cycle.

Figure 5 is an oscillogram of the voltage at (b) or the plate of tube B. With B conducting, (b) is first at a low voltage. The first pulse blocks B and causes a voltage rise at (b). On the second pulse B again conducts and the voltage at (b) drops. Again, the cycle is repeated for successive pulses.

The multigrid counter does not respond to positive pulses on the input grid. To illustrate this, suppose tube B is now conducting and tube A non-conducting. Let a positive pulse be applied to the point marked "input". Tube B will conduct slightly more than it has been, causing a further drop in potential at (b) and hence (d), making A more non-conducting. The positive pulse will also appear on grid #1 of A but since grid 3 (d) is at or beyond cut-off no change will take place in the plate current through A. A positive pulse on the grids of the counter will therefore have no effect.

With the circuit as shown on Plate 12, both tubes are continuously drawing screen current whereas only one plate is drawing current at a given time. It is possible to interchange the function of grid #1 and grid #3 in which case the non-conducting tube will draw neither plate nor screen current. This is advantageous from a power standpoint since the number of these stages used makes the saving appreciable. In the present system the circuit is as shown on Plate 12.

d. Two Stage Counter

For every switch made from B to A, a positive potential swing is developed at (b) and for every switch from A to B a negative potential swing is developed at (b). Thus out of two negative pulses originally impressed on the grids of the stage one negative pulse may be derived from the plate at (b). If the output of B at the point (b) is fed into another stage through a small coupling capacitance the second stage will trip only for the second transition of stage 1 since the counter does not respond to positive pulses on its control grid. It follows that stage 2 will trip once for every two transitions of stage 1 and if the output of stage 2 is fed into still another stage, stage 3 will trip once for every two transitions of stage 2 and every four transitions of stage 1.

In the triode counter, for every two negative pulses on the input a positive and negative potential swing is obtained at the plate which, if coupled into a second stage, will trip that stage twice. Thus no counting action is obtained. This can be remedied by placing rectifiers between stages to eliminate the positive or the negative pulses. This requires an extra tube per stage and nullifies the effect of using a double triode as a counter stage. For this reason and the advantages in resetting, only multiple grid counter and switch stages are used in the recognition system.

A counter of two stages will have four distinct states of equilibrium as follows:

| | Stage 1 | | Stage 2 | |
|---|---|---|---|---|
| | Conducting | Non-conducting | Conducting | Non-conducting |
| State 1 | B | A | B | A |
| State 2 | A | D | B | A |
| State 3 | B | [illegible] | A | D |
| State 4 | A | B | A | B |

In other words, a series of scale-of-2 counters becomes a scale-of-$2^n$ and by proper resetting of the individual stages it reduces to a scale-of-n counter. Thus the two stage counter above can be made a scale-of-four, scale-of-three, scale-of-two, or scale-of-one counter.

This is illustrated on Plate 14. Figure 1 shows the scale-of-four counter. Here no resetting is necessary. For every four negative pulses on the input, one output pulse is obtained. The scale-of-three counter is shown in Figure 2. The output pulse is applied to the tubes in such a way as to reset the counters to state 2 (see table above). Now three pulses on the input result in one output pulse. Similarly, in Figures 3 and 4, a scale-of-two and a scale-of-one counter are obtained by having the output reset to state 3 and state 4 respectively.

The operation of a two stage, scale-of-four counter is illustrated by Figures 3 to 8 of Plate 13. Figures 3 to 5 correspond to the first stage and Figures 6 to 8 to the second stage. In the first stage, corresponding to the 2nd and 4th input pulses (Figure 3) there are two negative potential swings (Figure 5). These are fed to the second stage and appear on the input grid as shown in Figure 6. Figure 8 is an oscillogram of the output plate voltage of stage #2 and shows a single negative potential swing corresponding to the 2nd pulse of Figure 6 and the 4th pulse of Figure 3.

The 1st and 3rd pulses of Figure 3 produce positive potential

swings in Figure 5 and very small pulses in Figure 6, since as noted above, this input grid immediately draws current on a positive pulse. There is, then, no transition in stage #2 for the 1st and 3rd pulses of stage #1.

e. Multi-Stage Counter

A three stage counter will have eight states of equilibrium and a six stage counter 64 states. These states are consecutive and, if the 64th state is used as an indication, a six stage counter may be used to count any number of pulses from one to 64 by resetting it to the appropriate state. For example, a count of one is obtained by resetting to the 63rd state, a count of 16 by resetting to the 48th state or a count of 60 by resetting to the 4th state.

In the recognition system the actual method of resetting is such that the counter can be made to reset to any desired state for both the challenge and the reply. Resetting is done at two periods during any cycle, one between transmission of a challenge and reception of the reply (or between reception of the challenge and transmission of the reply) and the other at the completion of the cycle. In this way it is possible to have a single counter serve as two counters, each of which can be pre-set to any desired state. The counter output will then be 64 minus the number of the state to which it is pre-set. This is how the coding of the signal is accomplished.

The actual mechanism of resetting can best be understood by again referring to Plate 12. Two methods of resetting are shown, both of which are used in the recognition system. These are:

(1) Cathode resetting. The cathode current is interrupted by a mechanical break using either a switch or a relay. If tube B is conducting and its cathode current is interrupted, tube A becomes conducting and remains so after the cathode of B is again closed. As shown, the SPDT switch enables a single resetting relay to make either A or B non-conducting depending on whether the switch is down or up. Resetting by those mechanical methods must necessarily be slow, the process requiring on the order of 0.01 second. It is possible to reset the cathodes electronically by placing a tube in series with the counter cathodes and bias or unbias it. This, however, has the disadvantage of producing a certain amount of dissymmetry (i.e., the cathode of one tube in a stage is operating at a higher potential than the other tube in the stage due to the voltage drop in the resetting tube) as well as requiring two or more power tubes to carry the total cathode current.

(2) Grid resetting. Another method of resetting is to apply a negative pulse of sufficient amplitude to cut off the desired tube. This is also shown on Plate 12. A SPDT switch determines which of the two tubes is to be left conducting. The grid which is used here for resetting is grid #5 (suppressor) which is rather insensitive, requiring about 100

volts to trip the counter. It is, of course, possible to reset using other grids but there is always the danger of interaction between the other circuits connected to the grid and the resetting circuit.

The grid resetting is used to set up the counter between a challenge and reply or between reception of a reply and transmission of a challenge. Resetting at this point is accomplished in about 10 μ sec. The reason for the fast resetting here is to make the challenge and reply signals indistinguishable from one another.

Cathode resetting is used at the end of a cycle at which point there is sufficient time to warrant the use of the slower cathode resetting. This could also be accomplished by grid resetting especially if another grid were available in the tube. To do it on one of the available grids would create enough interaction problems to make it more complicated than cathode resetting.

Resetting may also be accomplished by interrupting current in the plate circuit by methods similar to those used in the cathode.

The scale-of-64 counter used in the recognition system can be worked out on the same basis as the scale-of-four. Plate 15 shows the various states of the scale-of-64 for all combinations of resetting switches.

f. Electronic Switch

The electronic switch as it is used throughout the recognition system is in reality a scale-of-two counter. It is usually used with either the control grids tied to separate controlling circuits (not together as in the counter) or with just one control grid. The latter is used where an irreversible operation or insurance against more than a single operation is desired.

The switching or control of other circuits by the electronic switch is accomplished by one or more of the following three methods:

(1) The pulse output derived from the plate is used to control or trigger off another circuit as for example in resetting.

(2) The d-c potential on the counter plate is used as a plate supply or a bias supply for another tube. The counter plate approaches the plate supply when it is cut off and zero when it is conducting.

(3) The d-c potential on the transit grid (grid #3 on Plate 12) changes from zero for the conducting state to a large negative value for the non-conducting state. This change can be used to bias and unbias a tube.

Reference to the oscillograms on Plate 13 will show actual voltage changes for a typical switch.

4. Component Circuits

To simplify explanation, the keyer-recognizer is subdivided on a functional basis into the following major circuits:

a. Power supply
b. Keying circuit
c. Multivibrator
d. Counter
e. Final clearout circuit
f. Intermediate clearout circuit
g. Receiver amplifier
h. Amber light control circuit
i. Green light control circuit
j. Blinker control circuit

The relationship of these circuits to the complete cycles of operation is indicated in the following block diagrams:

For the challenge cycle - Plate 8
For the standby cycle - Plate 9
For the blinker cycle - Plate 10

The relationship of the various stages to the circuit subdivisions and the complete cycles is shown in the following schematic diagrams:

For the challenge cycle - Plate 16
For the standby cycle - Plate 17
For the blinker cycle - Plate 18

The sequence of operation of the various stages and their location on the keyer-recogniser front panel is shown on the following plates:

For the challenge cycle - Plate 19
For the standby cycle - Plate 20
For the blinker cycle - Plate 21

A complete circuit diagram of the keyer recogniser (excluding the power supply) is on Plate 23, and a circuit diagram of the power supply on Plate 24. The following detailed explanation of the keyer-recogniser circuit will be more easily understood by frequent reference to

the above-mentioned plates. The element and supply voltages of the various stages in the keyer-recognizer are given in Table 4.

a. Power Supply

A circuit diagram of the power supply is shown on Plate 24.

The power supply operates directly from the 115-volt, a-c line and delivers 6.3 volts a.c. to all tube heater elements and the following rectified d-c voltages:

(1) Negative bias voltage (Ec) 175 volts
(2) Screen grid voltage (Esg) +34 volts
(3) Plate voltage (Ep) 145 volts
(4) Multivibrator plate voltage (Emv) 230 volts

The terminal strip, numbered as shown in the diagram, is located under the chassis. The total power consumption of the keyer-recognizer assembly is 275 watts.

b. Keying Circuit

A circuit diagram of the keyer-recognizer is shown on Plate 23.

The function of the keying circuit is to initiate and end transmission by starting and stopping the multivibrator. The circuit includes the following stages:

(1) $T_3$, a gas-filled triode (2 4), operates at a fixed bias of 6.6 volts. The tube discharges a 0.05 mfd. condenser, one side of which is permanently grounded, the other side being normally grounded by the key in the control box. When this key is depressed the ungrounded point builds up, discharges through the 2 4, impressing a negative pulse on the grid of $S_{2a}$. These pulses also appear on the grid of the blinker inverter ($V_2$) and initiate clearout so that the blinker will not light on transmission. $T_3$ functions, on challenge, to delay the action of the keying circuit sufficiently so that the antenna switch will have operated to make contact with the directional antenna.

(2) $S_2$, an electronic switch using two 7Q7 pentagrid converters, makes a single transition during each cycle of operation and resets to its original state. Its function is to trip the MV and insure a single transmission by remaining in state 2 until final clearout. A negative pulse from $T_3$ trips $S_2$ and produces a negative potential swing on the plate of $S_{2b}$ causing a negative pulse to be applied to the control grid of $MV_a$ through the small coupling condenser. $S_2$ is reset when final clearout breaks the cathode ground of $S_{2b}$.

(3) MS, an electronic switch using two 7Q7's. The multivibrator switch may be compared to a double-throw switch in that it may be tripped in either direction, from state 1 to state 2 by a negative pulse on $MS_a$, or, from state 2 to state 1 by a negative pulse on $MS_b$. Its functions are (1) to unblock the multivibrator and start transmission when tripped by $S_2$; (2) to block the multivibrator and end transmission when tripped back by the counter output; (3) on challenge to initiate intermediate clearout when tripped by the counter output; and (4) to pulse the blinker circuit (B1) when tripped by $S_2$. The multivibrator is biased from grid 3 of $MS_b$; V3 (int. clearout circuit) is pulsed from the plate of $MS_a$; and $B_1$ is pulsed from the plate of $MS_b$.

c. Multivibrator

The multivibrator (MV) is a 6SC7 twin triode. A series of negative pulses generated by the MV appears on the plate of $MV_b$ and is fed to the transmitter through 500 mmfd. and to the counter through 25 mmfd. The circuit elements are chosen to give a pulse frequency of 20 kilocycles. An inductor of 30 microhenries in the plate circuit of $MV_a$ increases the pulse amplitude. Oscillograms of the wave form on both plates of the MV are shown on Plate 13, Figures 1 and 2.

The multivibrator is controlled by the application, on the grid of $MV_b$, of bias voltage from grid 3 of $MS_b$. By starting and stopping the multivibrator at the appropriate instants, any number of pulses may be generated and fed to the transmitter. A concentric line runs from the multivibrator output to the rear of the chassis and connects with a line to the transmitter.

d. Counter

$C_1$, $C_2$, $C_3$, $C_4$, $C_5$, $C_6$ – counter stages, each using two 7Q7 pentagrid converters.

The six stage counter used in the keyer-recognizer performs two operations during each cycle. It determines the number of pulses transmitted and counts the received pulses for recognition. To accomplish this, the counter must be reset twice during each cycle. First, the intermediate clearout operates by applying a large negative pulse to the suppressor grid of one tube in each stage, and then the final clearout operates by breaking the cathode ground of one tube in each stage. By means of a double-throw switch, the clearout mechanism may be connected to the appropriate element of either tube in a given stage and thus may reset that stage to state 1 or state 2 as desired. Two rows of toggle switches, located above the counter, perform this function in the keyer-recognizer. The lower row serves to connect the final clearout with one cathode in each stage and to ground the other cathode, thereby determining the first count in the cycle. The upper row serves to connect the intermediate clearout to

one suppressor in each stage, thereby determining the second count. The chart on Plate 15 shows the switch positions and initial counter states for every count from 1 to 64.

To summarize, the counter performs the following cycles of operation.

1. On challenge, it receives pulses from the multivibrator and stops the MV at the correct count by tripping the MVS from the plate of $C_{6b}$. The MVS now initiates intermediate clearout and the second count is set up. The received reply pulses are fed from the receiver amplifier (A1) and if their count is correct, C6 trips S, and recognition is indicated. Final clearout operates to reset to the first count and the counter is now ready to repeat the cycle.

2. On standby, the received challenge is fed from $A_1$ and if its count is correct $C_6$ trips $S_3$ and initiates intermediate clearout. The second count is now set up. The transmitted pulses are then fed to the counter which stops the multivibrator at the correct count. Final clearout operates to reset to the first count and the cycle is completed. Note that on challenge, the first count is transmitted and the second count received, whereas on standby, the first count is received and the second count transmitted.

e. Final Clearout Circuit

The function of the final clearout circuit is to reset the counter and electronic switches (excluding the blinker system) to their respective states for the beginning of a cycle. The state to which the counter is reset is determined by the lower row of coding switches. Final clearout is initiated by any one of the following: (1) the first transmitted pulse, (2) the first received pulse, (3) received interference of sufficient amplitude. It maintains the keyer-recognizer in a state for immediate operation by prompt termination of the working cycle after a sufficient time delay for complete operation and by resetting the keyer-recognizer when tripped by interference. The circuit includes the following stages:

(1) $S_1$ - an electronic switch using two 717's makes a single transition when tripped from the counter input by any of the three means listed above and is reset by the final clearout breaking the cathode ground of $S_{1b}$. The plate of $S_{1a}$ applies voltage to $T_1$ when tripped by a pulse on $S_{1a}$ control grid. ($S_1$ also operates in the amber light control circuit described on page 32 )

(2) $T_1$ - A time delay stage using a gas-filled triode (884) operated at a fixed bias of 7.6 volts. It discharges a 0.1 micro-farad condenser which builds up when plate voltage is applied from $S_{1a}$ through a 10-megohm resistor. Its purpose is to delay final clearout until

the operating cycle has been completed. When $T_1$ discharges, it sends a negative pulse to the control grid of $S_{5a}$.

(3) $S_5$ - an electronic switch using two 7Q7's makes a single transition when tripped from T1 and is reset by the final clearout breaking the cathode ground of $S_{5b}$. Its function is to unblock A2 when tripped and block after clearout. Grid 3 of $S_{5a}$ performs this biasing operation.

(4) A2 - Amplifier using one-half of a 6SC7 twin triode. When unblocked by S5 this tube draws current through the cathode-breaking relay.

(5) A d-c relay. Voltage is applied to the coil from $E_{av}$ when the low side is grounded through A2. The contacts are normally closed grounding the 7Q7 cathodes, this ground being broken when the coil is energised. A lead from the low side of the coil to the key in the control box allows the coil to be grounded when the key is raised and provides a means of manually initiating final clearout.

f. Intermediate Clearout Circuit

The intermediate clearout circuit operates to reset the counter to its second count. On challenge, it operates after transmission without time delay, to reset the counter to receive the reply. On standby, it operates after reception with a time delay sufficient to detect an overcount in the received challenge, to reset the counter for transmission. It delivers a large negative pulse to one suppressor grid in each counter stage (as determined by the upper row of coding switches) and to the suppressors of $S_{3b}$ and $S_{4a}$. The circuit includes the following stages:

(1) $S_3$ - an electronic switch using two 7Q7's makes four transitions during each cycle. On challenge, it is tripped from the counter output on the last transmitted pulse and then is reset by the intermediate clearout. $S_3$ is tripped a second time from the counter output on the last received pulse (of a correct count) and then is reset by final clearout. If, however, an extra pulse or overcount is received, $S_3$ is immediately tripped back before final clearout. This is achieved by feeding the control grid of $S_{3b}$ from the counter input and enables $S_3$ to detect received overcounts.

On standby, S3 is tripped from the counter output on the last received puls and then is reset by the intermediate clearout. If, however, an overcount is received S3 is tripped back immediately and clearout (and subsequent transmission) does not occur, since, on standby, intermediate clearout is initiated by S3. When correct count is received,

transmission follows and $S_3$ is again tripped by the counter output and is reset by final clearout.

To summarize, $S_3$ is tripped from its original state by a pulse from the counter output (plate of $C_{6b}$) impressed on the control grid of $S_{3a}$. When in state 2 it is tripped back or reset by any one of three means; (1) intermediate clearout operating on the suppressor of $S_{3b}$, (2) final clearout breaking the cathode of $S_{3b}$ or (3) an overcount pulse from the input fed to the control grid of $S_{3b}$.

Note that all transmitted and received pulses are impressed on the control grid of $S_{3b}$, but they have no effect until $S_3$ has been tripped to state 2 by the counter output. By this time, transmission and correct reception have been completed.

$S_3$ initiates intermediate clearout by applying voltage from $S_{3a}$ plate to the plate of $T_2$. It also operates in the green light control circuit, described on page 32.

(2) $T_2$ - a time delay stage using a gas-filled triode (3C4) operated at a fixed bias of 7 volts. On standby, it discharges a 250 micromicrofarad condenser which builds up when plate voltage is applied from $S_{3a}$ through a 3.3 megohm resistor. On discharge, $T_2$ feeds a negative pulse to the grid of V1. After clearout $T_2$ is blocked by $S_4$ applying bias voltage to the grid.

$T_2$ serves to introduce sufficient time delay in the intermediate clearout for $S_3$ to detect an overcount, if received. It does not operate on challenge when intermediate clearout is initiated by VVS in which case no time delay is employed.

(3) $V_1$ - inverter using one-half of a 6SC7 twin triode delivers a positive pulse to A3. On standby it receives a negative pulse from $T_2$; on challenge it is pulsed from $VVS_a$.

(4) A3 - amplifier using a 6SJ7 pentode is operated at 9 volts cathode bias. A positive pulse from V1 applied to the control grid of A3 produces a large negative pulse on the plate which is the pulse applied to the suppressors in the stages reset by the intermediate clearout. After clearout, A3 is blocked by $S_4$ applying bias voltage to the control grid.

(5) $S_4$ - an electronic switch using two 717's is tripped by intermediate clearout operating on the suppressor of $S_{4a}$ and is reset by final clearout breaking the cathode ground of $S_{4b}$. It serves to block $T_2$

and $A_3$ after they have operated in the intermediate clearout and thus insures only one clearout pulse. This is accomplished by applying bias voltage from grid 3 of $S_{4a}$ to the grids of $T_2$ and $A_3$, each through a 1-megohm resistor. Its second purpose is to initiate transmission on standby by tripping $S_2$. A lead from the plate of $S_{4b}$ feeds a negative pulse to the control grid of $S_{2a}$ when $S_4$ has been tripped by intermediate clearout. This, of course, occurs only upon a correct received count.

Since both $S_4$ and $V_1$ feed the control grid of $A_3$, there is an a-c path between the plate of $V_1$ and grid 3 of $S_{4a}$. To attenuate the positive pulse from $V_1$, a 500,000-ohm resistor is placed in series and a 250 mmfd. condenser to ground in the lead to $S_{4a}$.

A similar situation arises in that both $T_3$ and $S_4$ feed $S_2$. To prevent interaction between $T_3$ and $S_4$ the line from $T_3$ has two 50 mmfd. condensers in series and their junction returned to ground through 25,000 ohms.

The reset chart, Table 5, shows which tube in a given stage is blocked (made non-conducting) by the operation of the clearout systems. The blinker clearout operating on $B_1$, $B_2$, and $BS_1$, is discussed below on page 33.

g. Receiver Amplifier

$A_1$ - an amplifier using one-half of a 6SC7 twin triode operated with a cathode bias of 5.5 volts. Its purpose is to amplify and invert pulses fed through a lead from the receiver output. Positive pulses are fed to the control grid from the receiver and give rise to negative pulses on the plate which are fed into the counter and to $S_1$ and $S_3$. This point is referred to as the counter input or merely the input.

h. Amber light control circuit

(1) $S_1$ (see Final Clearout Circuit, page 29 ). It is tripped on any transmitted or received pulse or on interference of sufficient amplitude. A lead from grid 3 of $S_{1a}$ serves to unblock a 2050 tube when $S_1$ is tripped.

(2) A 2050 gas-filled tetrode with cathode and screen grounded. The plate circuit is in series with a transformer and the amber light. The tube is normally unbiased allowing current to flow through the circuit. When $S_1$ is tripped, the 2050 is blocked from grid 3 of $S_{1a}$ and the amber light goes out. On final clearout $S_1$ returns, the 2050 is unbiased and the amber light goes on.

i. Green Light Control Circuit

(1) $S_3$ (see Intermediate Clearout Circuit, page 30). A lead from grid 3 of $S_{3b}$ serves to unblock a 2050 gas tube in the green light circuit when $S_3$ is tripped. As noted before, $S_3$ makes four transitions

(is tripped twice and reset twice) in each cycle of operations. On the first transition, $S_3$ is reset too rapidly to give a visual indication on the green light. When tripped the second time $S_3$ is reset by final clearout after a considerable time delay (about one second) and the green light is visible during this interval.

(2) A 2050 gas-filled tetrode with cathode and screen grounded. The plate circuit is in series with a transformer and the green light. The tube is normally blocked, unblocking when $S_3$ is tripped, resulting in the green light going on. At final clearout $S_3$ is reset, the 2050 is blocked and the green light goes out.

j. Blinker Control Circuit

The blinker control circuit operates on standby and flashes a blinker light when three correct challenge counts have been received in close succession (overall time of less than 12 seconds). To do this, it must be initiated by a switch that trips, following recognition of a correct received challenge. The multivibrator switch performs this function. However, since the MVS is tripped on its own challenge, provision is made for clearing the blinker circuit on every transmitted challenge. This prevents the blinker from lighting when its unit is challenging. The circuit includes the following stages:

(1) $B_1$ and $B_2$ - counter stages using two 7Q7's each form a two stage, scale-of-three counter which is tripped by the MVS on each correct received challenge and is reset after reaching its fourth state. The blinker counter performs the following functions: (1) On the first transition it sends a negative tripping pulse to $BS_1$; (2) On the third transition it unblocks a pair of 2050's in the blinker light circuit; (3) On the third transition it applies sufficient plate voltage to discharge $BT_2$ (after a given time delay). Therefore, it requires three correct challenges from the other unit to cause three transitions of the blinker counter and finally flash the blinker light.

Table 6 gives the successive states of the blinker counter and the corresponding voltages applied to the stages controlled from the counter. $BS_1$ is tripped from the plate of either $B_{1a}$ or $B_{2b}$. The voltage applied to the 2050 grids is fed from grid 3 of $B_{1a}$ and grid 3 of $B_{2b}$ and is the mean of the voltages at the transfer grids of $B_{1a}$ and $B_{2b}$. In a similar manner the voltage at the plate of $BT_2$ is the mean of the voltages at the plates of $B_{1b}$ and $B_{2a}$. The counter is reset to state 1 by a large negative pulse from $A_4$ impressed upon the suppressors of $B_{1a}$ and $B_{2b}$.

(2) $BS_1$ - an electronic switch using two 7Q7's makes a single transition when tripped by either $B_1$ or $B_2$ and is reset by the blinker clearout operating on the suppressor of $BS_{1b}$. It has two functions

(1) it applies voltage from the plate of $BS_{1a}$ to $BT_1$ (slow clearout gas tube) and (2) it controls $D_1$ by blocking it while $BT_1$ is charging and unblocking it after clearout. This biasing voltage is applied from grid 3 of $BS_{1a}$.

(3) $BT_1$ - slow clearout time delay using a gas-filled triode (884) operated at a fixed bias of 3 volts. Plate voltage is applied from $BS_1$ through 3.6 megohms, and charges a 3 microfarad condenser which after about 12 seconds discharges through the 884 and feeds a negative pulse to the grid of $V_2$, initiating clearout. The purpose of this sta e is to provide sufficient time delay in the blinker clearout for the reception of three separate challenges.

(4) $BT_2$ - Fast clearout time delay using a gas-filled triode (884) operated at fixed cathode bias of 6 volts. Plate voltage is supplied through 3.6 megohms from the blinker counter ($B_1$ and $B_2$) when in state 4 as described above. When the 0.03 microfarad condenser is discharged by the 884, a negative pulse is fed to the grid of $V_2$ and clearout proceeds.

This stage is energised at the same moment that the blinker lights and on discharge it initiates clearout which blocks the blinker light circuit. It is evident that the time delay of $BT_2$ corresponds to the time of the blinker light flash.

(5) $D_1$ - A discharge tube using one-half of a 6SC7 twin triode. Its purpose is to help discharge the 3 microfarad condenser when the action of $BT_1$ is preceded by $BT_2$ and the former is inhibited. When $BT_1$ is charging, $D_1$ is blocked from grid 3 of $BS_{1a}$. The plate resistance, 5.6 megohms, is critical since it must limit the current drawn by $D_1$ when $BT_2$ is charging and yet allow sufficient discharge of the condenser when $BT_2$ is superseded by $BT_1$.

(6) $V_2$ - An inverter using one-half of a 6SC7 twin triode receives a negative pulse from any one of the following: (1) on challenge from $T_3$ in order to prevent blinker operation, (2) on standby from $BT_2$, after three correct counts have been received and the blinker lighted, and (3) on standby from $BT_1$ when the blinker cycle has been initiated but not completed within the 12-second time delay of $BT_1$. Its purpose is to supply a positive pulse to the grid of $A_4$.

(7) $A_4$ - Amplifier using one-half of a 6SC7 twin triode, operated at a fixed bias of 15 volts. When a positive pulse from $V_2$ is impressed on its grid, $A_4$ delivers the resetting negative pulse to the suppressors of $B_{1a}$, $B_{2b}$ and $BS_{1b}$.

(8) Two 2050's - gas-filled tetrodes with cathode and screen grounded and one plate connected to each end of the secondary of a transformer

operated from the 115-volt a-c line. A lead from the secondary center-tap delivers power to the blinker light when the 2050's are unblocked. As previously noted, the 2050 control grids are biased from the transfer grids $B_{1a}$ and $B_{2b}$.

k. Terminal Panel

The terminal panel is located at the front of the key-recognizer in the lower right corner. For connections to this panel see Plate 2.

SECRET

D. Propagation System

The propagation system includes the antennas and equipment located between the antennas and the receiver and transmitter, namely, the duplexer, the antenna switch, and transmission lines. The system has been designed and is tuned for a wavelength of 70 centimeters (corresponding to a frequency of 428.5 megacycles).

1. Duplexer

The duplexer is an arrangement which permits the use of a single antenna for transmission and reception. It is an electronic antenna switch which switches the antenna from transmitter to receiver (or vice versa) in approximately ten microseconds.

A schematic diagram of the duplexer used in this equipment is shown on Plate 2c. An actual photograph is shown on Plate 112.

To analyze the duplexer, consider first the case of a transmission. The signal feeds from the transmitter to point (a). If now the condition is fulfilled that the impedance presented by (a-b) is large with respect to that presented by the line (a-e) then the greater portion of the signal will feed into the antenna. That this condition is satisfied will be shown. The length of (a-b) is approximately an electrical quarter wavelength. Therefore if the line is shorted at (b) then the impedance of (a-b) at (a) will be very high. The shorting of (b) is accomplished as follows: The point (b) is tapped in on the quarter wave tank (c-f) at a point corresponding to an impedance $Z_1$ which is of the order of hundreds of ohms. Point (c) has an impedance $Z_2$, normally several thousand ohms. The first portion of the signal from the transmitter appears at (c) with its voltage transformed in the ratio of $\frac{Z2}{Z1}$ over that at (b). This voltage is sufficient to break down the gas tube at (c) with a consequent lowering of the impedance at (c) by about a factor of roughly 15. The impedance at (b) is lowered by the same factor resulting in an effective short at (b). Thus the transmitted signal is fed into the antenna with only a small percentage of it going into the receiver circuit due to the impedance at (b) not being zero. The receiver input stage then is subjected to the damaging transmitter output for only about $10^{-7}$ seconds (the breakdown time of the gas tube). After that time only a small portion of the transmitter output appears at the receiver. This serves as a very effective protection for the receiver input tube.

In the case of reception, the signal feeds from the antenna to point (a). The length (a-d) is made an odd number of quarter wavelengths with the point (d) shorted by the antenna coupling coil. This

makes the impedance of (a-d) looking into (a) very high. Most of the received signal then feed to (b). There will be some further loss at (b) since the impedance of the tank at (b) is about seven to ten times that of the line. This means about a ten percent loss. During reception the voltage at (c) is, of course, not nearly enough to break down the gas tube.

The gas tube used here is filled with helium at a pressure of about one atmosphere.

The overall efficiency of the duplexers is about 75% for the complete cycle.

2. Antenna Switch

The antenna switch is located in the transmission line system between the duplexer and the antennas. A photograph of it is shown on Plate 113 and a schematic on Plate 26. On standby the switch connects the duplexer to the non-directional antenna for both transmission and reception. This is its normal position. On challenge it connects the duplexer to the directional antenna for both transmission and reception. Three concentric lines enter the switch; one from each antenna and one from the duplexer. A shorting bar, moved by an a-c solenoid working against a spring is always in contact with the line from the duplexer. Leads from the solenoid coil go through the control cable to contacts on the key in the control box. When the key is depressed for challenge, the solenoid is energised and the shorting bar connects the directional antenna line to the duplexer. When the key is released, the contacts are broken and the shorting bar moves back to its normal position (connecting the non-directional antenna line to the duplexer).

As previously noted (page 27) on challenge, $T_3$ in the keyer-recogniser delays the action of the keying circuit sufficiently to insure contact with the directional antenna before transmission takes place.

The total time for a complete challenge cycle is only a very small fraction of the time the switch is thrown to the directional antenna line. Since both operations are initiated simultaneously, the cycle is completed before the switch returns to its normal position.

3. Transmission Lines

All transmission lines in the system are either 3/8" or 7/8" solid copper concentric transmission lines using steatite insulating beads and having a characteristic impedance of 72 ohms. At present the 7/8" line is used only on the Yagi antenna. If long lines are to be used on shipboard it would be advisable to use 7/8" line to reduce the losses and decrease the chances of voltage breakdown.

4. Non-directional Antenna

The non-directional antenna is a vertically operated skirted dipole. It is shown on Plates 27 and 114. The concentric line is terminated in the two dipole elements. The quarter-wave skirt serves to match the unbalanced line to the balanced antenna system. That is, it allows the outer conductor of the line to swing at the termination point and yet leave the line grounded beyond the quarter-wave skirt. A piece of polystyrene closes up the end of the skirt as well as the transmission line to make it watertight. This antenna has a resistance very nearly equal to that of the line (72 ohms). The antenna was matched to the line by means of the method discussed in Appendix B. For proper matching, the dipole lengths should be 16.5 cm. or 0.235 $\lambda$. The non-directional antenna is used on standby for both reception and transmission.

The standard vertical dipole (hypodermic) type of non-directional antenna is also satisfactory and can be used interchangeably with the skirted dipole described above. This type, shown on Plates 28 and 115, is perhaps easier to mount and would probably have a more uniform circular pattern. However, when tuning the hypodermic by the method of Appendix B, much more critical and unstable values were encountered. Taking down an antenna and remounting it, would apparently change the antenna constants. The skirted dipole on the contrary gave very reliable and consistent results. Nevertheless, when used interchangeably on the recognition system, the hypodermic operates satisfactorily with a somewhat higher receiver gain necessary.

5. Directional Antenna

The directional antenna is a modification of the Yagi antenna for beam power transmission at ultra-high frequencies. It is a vertical array of parallel half-wave elements, one driven and ten parsitic, arranged as shown on Plates 29 and 117. The driven element is usually called the "antenna" and is denoted by the letter (A). The entire array is referred to as the "Yagi". Six parasitic elements are equally spaced along the trace of a parabola of which the focus is the driven element (A) and the focal distance is a quarter wavelength. These are the six reflectors, each denoted by the letter (R). The two end reflectors are at the points where the latus-rectum intersects the parabola and consequently a half wavelength each from (A). The four remaining parasitic elements are equally spaced along a line from the driven element (A) in the direction of propagation. These are the directors, each denoted by the letter (D). The first director is 3/8 or 26.25 cms. from (A) and each succeeding director is 3/8 farther. The various elements are rigidly supported at their correct spacings.

The antenna is tuned by varying the element lengths, the reflectors and directors being varied as a group. The dimensions are given for each half element or the nominal quarter wave measured from a

horizontal plane through the element mid-points. The elements are symmetrical above and below the central plane. The present element lengths in centimeters and fractions of a wave length are:

| | R | | A | | D | |
|---|---|---|---|---|---|---|
| | Cms. | λ | Cms. | | Cms. | |
| Yagi #1 | 16.9 | 0.241 | 15.1 | 0.216 | 14.5 | 0.207 |
| Yagi #2 | 16.9 | 0.241 | 15.3 | 0.219 | 14.4 | 0.206 |

The driven element or antenna (A) is fed from a 3/8" copper concentric line through a quarter-wave matching section. A diagram of the directional antenna feed system is shown in Figure 30. This quarter-wave section has a characteristic impedance of 42 ohms and serves to match the 72-ohm concentric line to the 25-ohm Yagi. The central conductor of the matching section is connected to the lower antenna half element and the outer or ground conductor to the upper half element. The antenna is mounted on a cylinder, through which the concentric line enters at the support end. The section of this cylinder from (A) to the support forms a quarter wave inverted skirt, open at (A) and shorted to ground, $\lambda/4$ from (A) at the support. This serves the same purpose as the skirt on the non-directional antenna discussed above. The 3/8-inch line is coupled to a 7/8-inch line which goes through a water-tight (not gas-tight) joint (See Plate 118) to allow rotation of the Yagi. A photograph of the complete antenna is shown on Plate 116. The Yagi is used on challenge to send a reinforced directive beam at the ship to be challenged and also serves as a collector for the reply. A directive pattern of the Yagi is shown on Plate 31.

## V. TUNING AND ADJUSTMENTS

Tuning and adjustment directions must necessarily be given for a recognition system consisting of two complete units, as the tuning of a single unit has little meaning or value. The two units are located at two fixed stations at least eight miles apart to eliminate saturation of the receivers at moderate gain settings. The units are referred to as Unit 1 and Unit 2 and their corresponding parts similarly designated such as transmitter 1, receiver 1, directional antenna 1, etc.

Three considerations involved in correct tuning are listed in the order of their relative importance.

1. Correct transmitted and received signal count.
2. Minimum frequency shift between transmission with directional and non-directional antennas.
3. Maximum signal transmission.

The necessary apparatus, in addition to the two recognition units, includes a cathode-ray oscilloscope at each station and a means of auxiliary communication between the two stations

The discussion on tuning is broken up into three parts; "adjustments", "method" and "procedure". Under "adjustments" the location of the various tuning controls are listed. The "method" paragraph deals with the method of tuning the individual units. The actual proce s of tuning up the entire system is discussed under "procedure".

### Tuning Adjustments

#### Transmitter:

1. The antenna loop tuning plunger located at the rear of the cabinet is advanced and retracted by means of a rod supplied with the unit and located inside the cabinet at the rear right hand side.

2. The oscillator filament tuning frames are reached through holes located below the plunger in the rear panel of the cabinet. The tuning frame shafts are rotated by means of a screw driver.

#### Receiver:

1. The oscillator tuning frame shaft extends beyond the rear panel on the right hand side and is rotated by means of a knob. A fixed scale, calibrated in degrees gives its relative position. When the total rotation is more than 360° the number of complete turns must be counted.

2. The preselector tuning shaft is reached through a hole in the left hand side of the cabinet and rotated by means of a long shank screw driver.

3. The gain control shaft extends beyond the rear panel on the left hand side and is rotated by means of a knob. A fixed scale calibrated in degrees gives the gain setting. Maximum gain corresponds to a setting of 300 degrees.

Duplexer:

1. The length of the resonant tank and its central conductor may be varied by means of extensions on both. Since b-f (Plate 26) is fixed, the values are given for the length b-c.

Tuning Method:

Assume units 1 and 2 installed, operating and set up for identical counts. (The count 32-32 has been found convenient for test work.) Connect the oscilloscope leads to the receiver output jacks located at the rear panel below the gain control. Adjust the oscilloscopes to read the signal deflections. Transmitter 1 is tuned by noting its plunger and filament tuning positions and the signal strength and pulse count at receiver 2. Transmitter 2 is tuned by noting its plunger and filament tuning positions and the signal strength and pulse count at receiver 1.

The following method is used for tuning the receiver to the incoming signal. First, the transmitter high voltage of the receiving unit must be turned off. This is obviously necessary, since the received signal initiates transmission and the signal strength of the reply in its own receiver is more than sufficient to saturate. Set the oscillator to 20 turns counterclockwise from its extreme clockwise position and the preselector to 26 turns counterclockwise from its extreme clockwise position. Raise the gain setting and adjust the oscillator tuning until a sizeable deflection (over 10 mm.) is noted on the scope. Then successively reduce the gain and tune the oscillator until a maximum deflection of 10 millimeters is reached. It will be noted that as the gain decreases the oscillator tuning moves counterclockwise. Now, with the gain setting fixed, tune the preselector for maximum signal and then retune the oscillator. When the oscilloscope deflection is 20 mm. or above, the gain should be reduced and the oscillator returned since deflections above 20 mm. are in the region of receiver saturation.

This procedure is followed for each change in transmitter tuning and is referred to merely as tuning the receiver. The oscillator tuning

position and the gain setting are read from their respective dials. Correct count is noted, as in operation, by the green light coming on.

Tuning Procedure:

Having discussed the method of tuning the individual units, the overall system can be tuned up by the following procedure, with each step taken in the order listed:

1. Set the oscillator filaments at (1) and (2) to 25 turns, counterclockwise.

2. Set the duplexer tank length at (1) to 15.8 centimeters.

3. Transmit from (1) on the non-directional antenna and:

   a. Tune the receiver at (2) adjusting duplexer at (2) for maximum signal. This must be carefully done since the duplexer tuning is quite critical.
   b. Adjust plunger at (1) for maximum signal at (2), within the limits of correct count.
   c. Tune the transmitter filaments at (1) for maximum signal within limits of correct count. The filament tuning is not at all critical; it will not seriously affect the output over a broad tuning range.

4. Transmit from (1) alternately on the direction and non-directional antennas and tune the plunger at (1) for minimum frequency shift as noted by the receiver oscillator tuning at (2).

5. Transmit from (2) on the non-directional antenna and:

   a. Tune the receiver at (1) adjusting duplexer at (1) for maximum signal.
   b. Adjust plunger at (2) for maximum signal at (1) within the limits of correct count.
   c. Tune the transmitter filaments at (2) for maximum signal within the limits of correct count.

6. Transmit from (2) alternately on the directional and non-directional antennas and tune the plunger at (2) for minimum frequency shift as noted by the receiver oscillator tuning at (1).

In the above procedure, it is, of course, necessary to retune the receiver in the receiving unit whenever any change is made in the transmitting unit.

## VI. HISTORY

### A. Origin

A pulse type recognition system having multiple groups of pulses and using electronic counters was first suggested by Commander Safford. On the basis of this suggestion Dr. Cleeton first set up a breadboard model of an experimental triode counter system to demonstrate the feasibility of this method. He then expanded this circuit, using pentagrid instead of triode counters, into a completely automatic, two way recognition system. The automatic operation was obtained through the use of numerous mechanical relays. A preliminary report on this system was made before any construction work was begun on it. It is filed as letter report S-S67/33, Serial 111, of January 17, 1939. After undergoing considerable changes this relay operated system resulted in the circuit described below under the heading "two group, four counter, relay operated system".

In the following paragraphs several systems are discussed which preceded the final model. No attempt is made here to explain these circuits in detail. They are included to show the background upon which the present system was built and, by comparison, the improvements which were made, as well as for purposes of record. Only the keyer-recognizer circuits are discussed since the rest of the system remained essentially the same.

### B. Two group, four counter, relay operated system

The original idea was to have each signal consist of two groups of pulses, with the challenge coded differently than the reply. The simplest way this could be achieved was to use a total of four counters, two for the challenge and two for the reply. Five stage counters were used, allowing a count up to 32 for each group. This gave 1010 possible codes on the challenge and an equal number on the reply, or a total possible number of 1,020,100 different codings.

The circuit diagram for the relay operated system is shown on Plate 32. This circuit required 61 vacuum tubes, 5 gas tubes, 3 relays, most of which had to make and break more than two circuits, and a stepping relay for the optical reply. A power supply large enough to deliver 500 ma. at 300 volts was necessary.

This system was made to work after a fashion but the relays were constantly giving some kind of trouble. The biggest problem was to keep the making and breaking of the relays from producing interference which would trip the counters. It must be remembered that a receiver was mounted on the same chassis as the relays, necessitating exceedingly good filtering across the relay points. Furthermore, since counters and switches are threshold devices, the appearance of even a single pulse at the

keyer-recogniser input was sufficient to upset the entire system. If a spurious pulse of this type had appeared regularly during each cycle, it could have been compensated for. However, since some of the relays were breaking sixty cycle currents, the appearance of interfering pulses would depend on what time during the AC cycle the relay was broken. DC operation of certain relays and lamps would have eliminated this. The added complication of large enough rectifiers to obtain the DC was not considered practical. Another undesirable feature of the relay system was that the delay between a reception and a reply was so long that the two could be distinguished with the aid of a pair of earphones.

In view of all these shortcomings, the relay system was converted to an electronic one in which all but one single circuit relay was eliminated.

The original system was also to have the added feature of operating on two carrier frequencies, one of which was to be in the region 400-450 Mc and the other between 150-200 Mc. Two receivers and two transmitters were to be used. At the transmitter end the higher frequency was to give directivity and the lower to be variable and have very high power capabilities. The output of the two receivers was to be fed through coincidence tubes so as to necessitate the simultaneous reception of the signal on both frequencies. The reason for this was that the variable frequency and the higher power were more easily obtainable at the lower frequency and the higher directivity more readily attained (i.e., it takes less space) at the higher frequency. By combining the two into a coincidence system, additional security was obtained because of the two frequencies, one of which can be changed from time to time. On a pure probability basis, the one million codes obtainable in the two group systems could by this method be increased to many millions. It therefore would be more difficult to interfere with such a system because the interfering signal would have to be on two frequencies. Similarly there should be less interference from certain types of static. From a practical standpoint, however, such a system presented sufficient disadvantages to make it felt that a one-frequency system would, all things considered, be superior to a two-frequency system. The reasons for this were as follows:

1. The two frequency system would require two complete transmitters and two complete receivers. This would add at least 30% to the size, the weight, and the power consumption. The additional complexity would certainly decrease the reliability of the system.

2. An additional non-directional antenna, as well as another duplexer, would be needed. The latter would have to be two to three times as large as the present duplexer. The whole system would have three antennas to mount, necessitating the running of three transmission lines.

3. Although it is more difficult to interfere with (interference is here used in the sense of someone else trying to operate the system) such a system, it is easier to jam it. The system can be rendered useless by the blocking of either receiver. The probability of an enemy being able to produce a jamming signal on any one of two frequencies is greater than his being able to produce a jamming signal at a given frequency.

4. Using two frequencies reduces by more than twice the degree of radio silence maintained. Whereas in the present system there is one direction and one non-directional transmission during a complete cycle, the two frequency system would have three non-directional and one directional transmission.

Operation on 175 Mc and 435 Mc was actually accomplished with the four counter relay system. However, with the development of the completely electronic system the two frequency idea was dropped for the reasons enumerated above. Should it be felt that the additional security is desirable in spite of the added size and complexity, the additional frequency can be added to the present system.

C. Two Group, Four Counter Electronic System

The relay system was completely rebuilt, eliminating all relays with the exception of one single circuit relay for the purpose of "error" or final clearout. Vacuum tube electronic switches are used to replace the relays. The circuit diagram is shown on Plate 33.

The circuit used 66 vacuum tubes, 2 gas tubes and one relay. Power consumption was very nearly that of the relay system. It had the same possible number of codes as the relay system.

The indication of correct transmission and reception was obtained by means of four neon lamps connected directly across the plates of four electronic switches. Each lamp corresponded to one group so that a check was maintained on the correctness of the transmission and reception of each group of any of the outgoing or incoming two groups.

Very satisfactory operation was obtained with this system. Two units were operated over a land distance of eight miles. The two units, however, after having undergone many experimental revisions (including the major one from relay to electronic switching) were in rather poor mechanical condition. It was therefore decided to build two new units with the two group system replaced by a one group system. The former was

to be held in reserve in case a greater coding was desired in an emergency (as called for in the authorization). All development and testing could then be carried out with the one group system and whenever the necessity arose the one group keyer-recognizer could simply be replaced by the two group. This system is discussed below under "one group, two counter electronic system."

D. <u>One Group, Two Counter Electronic System</u>

By changing from a two group to a one group system, the coding possibilities were reduced from approximately one million to about four thousand. However, this was done with a decided reduction in size and complexity of the circuits involved. Whereas the previous system had a total of 68 tubes in the keyer recognizer, the single group system needed only 39. The circuit diagram for the one group, two counter system is shown on Plate 34.

The neon lamps were replaced by a double electron ray tube as an indicator. A single relay was again used for cathode clearing.

This circuit was not built up because of the development of the further simplification of having one counter do double duty. Its operation is essentially the same as that of the one group, one counter system. The operation is simpler than the one counter method but it requires more tubes.

E. <u>One Group, One Counter Electronic System</u>

The one group, one counter system was the final model arrived at and is the one which has been discussed at length in this report. It uses a total of 47 tubes in the keyer-recognizer. This, however, includes a blinker and remote control system which was not included in the other systems. The actual number of tubes and relays used in the basic circuits of the keyer-recognizer would compare as follows for the various circuits:

| | Tubes | Relays |
|---|---|---|
| Four Counter, Two Group Relay System | 66 | 8 |
| Four Counter, Two Group Electronic System | 68 | 1 |
| Two Counter, One Group Electronic System | 39 | 1 |
| One Counter, One Group Electronic System | 33 | 1 |

In making the above comparison it must be borne in mind that the first two systems have a total possible coding of over a million whereas the last two have a coding of only slightly more than 4000.

## VII. GENERAL CONCLUSIONS

### A. Reliability

The two units were tested at various intervals over a period of about two months. During this period very reliable operation was maintained (with the exception of local interference troubles to be discussed below). These tests were made over a line of sight, land distance of about eight miles. The poor conducting medium over which the propagation was made, the low antenna heights used as well as the receiver gain which was still available made it reasonable to predict a range of 20 miles over sea water with the antennas mounted fairly high on a ship.

In conducting these tests it was necessary to transport one of the units a road distance of about fifteen miles, set it up, take it down at the conclusion of the test and transport it back again. This method does not lend itself very well to a reliability test. Normally out of about 100 challenges that were made, on the order of one error was obtained. This could usually be proven to have been interference of some kind. When one unit was set up for a count different than the other, the error detection system worked perfectly. No correct indication was received when a wrong count set-up existed.

No long time reliability test has been made because of the impossibility of finding any place to permanently set up the second unit. Neither have any tests been conducted to determine the effect of temperature and humidity changes. These units were built as first models to determine the operation of the switches and counters, the effect the RF circuits would have on them, the effect of interference, necessary transmitter power and receiver sensitivity to cover the range, etc. Consequently no special attempt was made to provide the transmitter, for example, with an overall zero temperature coefficient. It was assumed that once satisfactory operation had been effected, the stability, breakdown and other problems presented by temperature, humidity and life could be handled by the usually accepted methods.

### B. Interference

The problem of interference at times proved to be very troublesome. In all tests one of the units was set up on the Laboratory roof, while the other was usually taken out in the truck about eight miles from the Laboratory. At the latter point there was only one type of interference noticed which suspended operations. That was the approach of a car or truck to within about 50 feet of the antennas. The ignition interference would trip the counters and consequently cause the amber light to go out.

At the Laboratory, however, the interference problem was more serious. First of all, the same ignition interference was noted. The

various construction projects on the Laboratory grounds used engines and trucks, the interference from some of which caused trouble over a distance of 200 feet. Secondly, experimental transmitters with high peak power outputs (principally for Radar use) at a frequency near that of the recognition unit would produce interference. This occurred even though the Laboratory unit was operating at a receiver gain between 15 and 20 db below that of the receiver in the other unit. This high noise level at the Laboratory was, of course, also very noticeable in the regular communications receivers. The 200 Mc Radar produced no noticeable interference

In view of these interference difficulties the following recommendations are made:

1. A test on shipboard be conducted with the present two units to see if any interference difficulties are encountered. It is reasonable to assume that the noise level on shipboard is very much below that at the Laboratory in view of the long distance communication that a ship must maintain. If any source of interference such as ignition or other sparking exists on shipboard it can no doubt be suppressed. Furthermore, the added antenna height and salt water path will probably allow the receivers to be operated at lower gain.

2. If it is desired to have the units operate through such high levels of noise as are encountered at the Laboratory, then it will be necessary to increase the transmitter power by a factor of at least four times. Since the transmitter is already operating at 6000 volts, such an increase would mean a considerable increase in size and weight.

It is to be noted that the interference which is discussed here merely renders the system inoperative and does not cause it to give incorrect information. The presence of interference is immediately indicated by the flashing of the amber light.

C. Detectability

The recognition signal appears as a single click in a pair of earphones on a receiver tuned to the transmitter. It is necessary that the receiver have a band width of at least 50 KC for the signal to be at all resolved and at least 300 KC to pass it undistorted. Since the pulse frequency is 20 KC this signal could only be recorded by photographing it on some type of single sweep cathode ray tube setup. Therefore, even after the enemy does suspect the "click" as a signal of some kind, he is put to considerable trouble in breaking it down. He is then confronted by the big problem of trying to reproduce it. The 20 KC modulation frequency could, with a few additions, be raised as high as 200 KC if so desired, reducing the length of time the signal is on the air as well as making recording more difficult.

In view of the fact that an enemy must:

1. be in the line of sight to be within the signal range,
2. locate the carrier frequency,
3. recognise the signal as something other than interference,
4. record the signal on a high voltage single sweep oscillograph,
5. analyse the recorded signal,

it is very improbable he will detect the signal. This approaches very nearly the ideal situation of a recognition system which maintains radio silence.

D. Automatic Operation

There is very little that can be done to the present units to make the operation more automatic than it is. The only possible addition would be the use of some automatic means of rotating the directional antenna, although this would produce only a somewhat questionable improvement over the manual rotation. Perhaps the least reliable of the present automatic devices is the antenna switch. With some further research on the subject it is possible that this could be changed to electronic operation. The operation of the entire unit could then be made electronic with no moving parts except the main challenge switch.

E. Size and Weight

The equipment as it now stands has a volume of about 10 cubic feet. The authorization calls for a volume of 6 cubic feet or less. It was found that this figure could not be met without sacrificing some of the desirable features of the system. Of the 10 cubic feet, 2 are taken up by the ventilating system. The ventilating problem was not entirely appreciated at the beginning because it was not expected that such complete shielding would be necessary. The shielding made the ventilation problem more difficult, resulting in a demand for more space.

By using the improved counter circuits discussed on page 22, a considerable saving in power supply space would be effected. However, the total amount of decrease in size and weight that could be effected in the present system is not very great. The reason for this is that the receiver and transmitter at present account for more weight and space than the keyer-recogniser. To decrease the size of the transmitter, it would be necessary to discard the present relay type of operation in favor of some system using synchronised signals, as e.g., a system using a cathode ray tube. As previously mentioned, the development of this type of system is being carried on.

## VIII. APPENDIX

### A. Test Method for Determining the Transmitter Peak Power Output

The circuit reduces to a condenser discharging through a resistance load. The voltage decrease across the condenser is a measure of the energy input to the oscillator. The oscillator efficiency was measured under continuous pulsing with a lamp load. The current flowing is:

$$i = c\,\frac{de}{dt}$$

where
- $i$ = current drawn by load
- $c$ = capacity of condenser
- $e$ = condenser voltage
- $t$ = time of discharge

For a square wave* signal, the following may be assumed:

$$i = c\,\frac{\Delta e}{\Delta t}$$

where $\Delta t$ is the product of the pulse width by the number of pulses and $\Delta e$ is the voltage drop in time $\Delta t$.

For $c$ = 2 mfd, $\Delta e$ = 160 volts, $n$ = 64 pulses, and $\Delta t = 64 \times 7.5 = 480$ u sec.

$$i = 2 \times 10^{-6} \times \frac{160}{480 \times 10^{-6}} = 0.667 \text{ ampere}$$

$P_{in}$ = power input = $ei$ = 6500 x 0.667 = 4333 watts

$P_{out}$ = power output = $P_{in}$ x eff. = 4333 x 0.20 = 866 watts

*The modulating signal is not strictly a square wave signal, but is a good approximation (see Plate 4). The average pulse width is 7.5 microseconds.

B. **Method of Tuning Antennas**

The development and tuning of antennas that could be successfully used with the recognition unit presented an important problem.

The major consideration was one of matching. A mismatched antenna produces three undesirable effects. (1) The signal is reflected back into the transmitter and from the transmitter to the keyer-recognizer. The effect is a jamming of the keyer-recognizer which gives rise either to an incorrect transmitted count or to premature action of the electronic switches or both. (2) A mismatched antenna shifts the frequency of the oscillator from that of a properly matched antenna. Since the recognition system switches antennas, it is important that the antennas be matched so that no frequency shift results. (3) The energy radiation is reduced below that of a matched antenna.

Consider an RF oscillator feeding an antenna through a transmission line. The characteristic impedance of the line is

$$Z_o = \sqrt{\frac{R + j w L}{G + j w C}}$$

at frequencies as high as 400 Mc. $wL > R$ and $wC > G$. Hence, the characteristic impedance reduces to a pure resistance.

$$Z_o = R = \sqrt{\frac{L}{C}}$$

If the antenna is a pure resistance which is equal to that of the line, all the power in the line will be fed into the antenna. However, if the antenna is either an impedance, or a resistance different from that of the line, a reflection will take place and only part of the power will be fed into the antenna. The result will be standing waves on the line. The positions of the loops and nodal points along the line are determined by the angle of the antenna impedance whereas their amplitude is determined by how much the absolute value of the antenna impedance differs from the line resistance. It is, of course, desired to make the antenna a pure resistance so as to maximize the power fed from the pure resistance line to the antenna. This can be done by terminating the transmission line in any known pure resistance and obtaining a nodal reference point. For any value of resistance there will be only two such points. One will correspond to any resistance less than that of the line, the other to any resistance greater than that of the line. These two points will be 90° apart. The simplest cases are those of a shorted line and an open line corresponding to a zero and an infinite resistance. To properly match an

antenna to the line, it is merely necessary to establish the nodal reference points, adjust antenna constants until one or the other node point is reached and then, if possible, adjust further without shifting the node point to obtain a standing wave ratio approaching unity. If an adjustment is reached which has a high standing wave ratio and a slight change in the antenna produces a shift of 90° in the nodal points, then the antenna has a resistance very nearly equal to that of the line. It must be remembered that it is not necessarily possible to reduce the antenna resistance to that of the line. A matching section may be necessary. The resistance of a directional antenna can usually be varied over quite a range but it is done at the cost of changes in the directivity pattern. For best directivity, the radiation resistance of a directional antenna will usually be quite low, necessitating a matching section from a standard 75 ohm line.

The actual apparatus included an oscillator, operating at the signal frequency of the recognition system, feeding the antenna under test through a concentric line of enlarged cross-section. A diode detector moved laterally along the line measured the voltage between inner and outer conductors. By this method, the antenna element lengths and feed systems were adjusted to make the antenna impedances pure resistances equal to the line resistance of 75 ohms. The element lengths of the various antennas so obtained and the maximum standing wave ratios obtained were as follows:

1. For the skirted dipole (non-directional) antenna, a ratio of 0.90 was obtained at the following element lengths; dipoles - 16.5 cms., skirt - 17.0 cms.

2. For the hypodermic (non-directional) antenna, a ratio of 0.92 was obtained at the following element lengths: upper element - [illegible] cms., lower element - 15.2 cms. As previously pointed out, no consistent results were obtained with this antenna.

3. For Yagi #1 (directional) antenna a ratio of 0.96 was obtained at the following element lengths: (A) antenna - 15.1 cms., (R) reflectors - 16.9 cms., (D) directors - 14.5 cms.

## Table 1

### General Specifications

1. Signal Frequency - 428.5 megacycles
2. Range of operation - 20 miles (ship to ship)
3. Supply voltage - 110 to 120 volts 60 cycle a-c.
4. Peak power output - 360 watts
5. Total possible coding - 4096
6. Modulation Frequency - 20 kilocycles
7. Pulse Width - 7.5 microseconds
8. Total cycling time - 1 second
9. Blinker flash time - 1/4 second
10. Blinker cycling time - 12 seconds
11. Transmitter Plate Supply Voltage - 6500 volts
12. Number of tubes - 62 (See tube complement, Table 2)
13. Power consumption

| | |
|---|---|
| Total for Unit | - 675 watts |
| Transmitter | - 275 watts |
| Receiver | - 60 watts |
| Keyer-recognizer | - 250 watts |

14. Dimensions of cabinet:

    Width - 22", Depth - 13", Height - 45",
    Volume - 10.3 cubic feet

15. Weights

| | |
|---|---|
| Transmitter | - 73 lb |
| Receiver | - 15.5 lb |
| Keyer-recognizer | - 75 lb |
| Cabinet & Blower | - 13[illegible] lb |

Total Cabinet assembled 3[illegible]2.5 lb.

## Table 2

## Tube Complement

| | Number of Tubes |
|---|---|
| **Transmitter** | |
| HK24 Gammatron | 4 |
| 807 Amplifier Tetrode | 1 |
| 879 Half Wave Rectifier | 1 |
| 5T4 Full Wave Rectifier | 1 |
| Total | 7 |
| **Receiver** | |
| 6AC7 Amplifier Pentode | 4 |
| 6SJ7 Amplifier Pentode | 1 |
| 954 Detector Pentode (Acorn Type) | 1 |
| 955 Oscillator Triode (Acorn Type) | 1 |
| 5Z4 Full Wave Rectifier | 1 |
| Total | 8 |
| **Keyer-recognizer** | |
| 7Q7 Pentagrid Converter | 30 |
| 6SC7 Twin-triode Amplifier | 4 |
| 6SJ7 Amplifier Pentode | 1 |
| 884 Gas Triode | 5 |
| 2050 Gas Tetrode | 4 |
| 5V4G Full Wave Rectifier | 2 |
| 5Z4 Full Wave Rectifier | 1 |
| Total | 47 |
| Total for Unit | 62 |

## Table 3

### Receiver Voltages

| Stage | Plate Supply (Volts) | Plate (Volts) | Screen (Volts) | Cathode (Volts) |
|---|---|---|---|---|
| Oscillator - 955 | 270 | 185 | | 0 |
| 1st Detector - 954 | 270 | 255 | 30 | 7.3 |
| 1st I-F (at minimum gain | 270 | 265 | 255 | 9.0 |
| 6AC7 (at full gain | 270 | 245 | 183 | 5.0 |
| 2nd I-F (at minimum gain | 270 | 260 | 225 | 9.0 |
| 6AC7 (at full gain | 270 | 245 | 160 | 5.0 |
| 3rd I-F - 6AC7 | 270 | 230 | 100 | 1.2 |
| 2nd Detector - 6AC7 | 290 | 260 | 120 | 4.4 |
| A-F Amplifier - 6SJ7 | 290 | 145 | 46 | 0 |

All control grids are at zero voltage.

Minimum gain and full gain refer to the settings of the gain control resistor.

## Table 4

### Keyer-Recognizer Stages
### Element and Supply Voltages

| Stage | Plate Supply (Volts) | Plate Voltage (Volts) | Screen Voltage (Volts) | Control Grid Voltage (Volts) | Cathode Voltage (Volts) |
|---|---|---|---|---|---|
| $T_1$ | 20 or 120 | 3 to 60 | | -7.6 | 0 |
| $T_2$ | 34 or 120 | 23 to 52 | | -7.5 or -24 | 0 |
| $T_3$ | 150 | 0 to 50 | | -6.6 | 0 |
| $BT_1$ | 20 or 120 | 9 to 70 | | -8.0 | 0 |
| $BT_2$ | 20 or 120 | 7 to 37 | | 0 | 5.3 |
| $D_1$ | 9 or 70 | 0 to 45 | | 0 or -40 | 0 |
| $A_1$ | 145 | 145 | | 0 | 5.5 |
| $A_2$ | 230 | 230 | | 0 or -40 | 0 |
| $A_3$ | 230 | 205 | 145 | 0 | 9.4 |
| $A_4$ | 230 | 230 | | -15 | 0 |
| $V_1$ | 145 | 90 | | 0 | 0 |
| $V_2$ | 230 | 135 | | 0 | 0 |
| $'V_B$ | 230 | 230 | | 0 | 0 |
| $'V_A$ | 230 | 160 | | 0 | 0 |

All switches and counter stages:

| | |
|---|---|
| Plate supply | 145 volts |
| Plate voltage | 20 or 120 |
| Grid 3 supply | -175 |
| Grid 3 voltage | 0 or -40 |
| Screen voltage | 34 |
| Control grid voltage | 0 |
| Cathode voltage | 0 |

Table 5

Reset Chart

A is chosen so that the first transition changes it from conducting to non-conducting.

| | Intermediate Clearout Suppressor Reset | Final Clearout Cathode Reset | Blinker Clearout Suppressor Reset |
|---|---|---|---|
| $C_1$ | A or B | A or B | |
| $C_2$ | A or B | A or B | |
| $C_3$ | A or B | A or B | |
| $C_4$ | A or B | A or B | |
| $C_5$ | A or B | A or B | |
| $C_6$ | A or B | A or B | |
| $S_1$ | None | B | |
| $S_2$ | None | B | |
| $S_3$ | B | B | |
| $S_4$ | A | B | |
| $S_5$ | None | B | |
| WS | None | B | |
| $B_1$ | — | — | A |
| $B_2$ | — | — | B |
| $BS_1$ | — | — | B |

SECRET

## Table 5

### Reset Chart

The tubes indicated in the reset columns below indicate which tube in a stage is made non-conducting for the respective reset operations. The stages and tubes listed are shown in the circuit on Plate 23.

| Stage | Intermediate Clearout Suppressor Reset | Final Clearout Cathode Reset | Blinker Clearout Suppressor Reset |
|---|---|---|---|
| $C_1$ | A or B | A or B | |
| $C_2$ | A or B | A or B | |
| $C_3$ | A or B | A or B | |
| $C_4$ | A or B | A or B | |
| $C_5$ | A or B | A or B | |
| $C_6$ | A or B | A or B | |
| $S_1$ | None | B | |
| $S_2$ | None | B | |
| $S_3$ | B | B | |
| $S_4$ | A | B | |
| $S_5$ | None | B | |
| MVS | None | B | |
| $B_1$ | — | — | A |
| $B_2$ | — | — | B |
| $BS_1$ | — | — | B |

## Table 6

### States of Blinker Counter

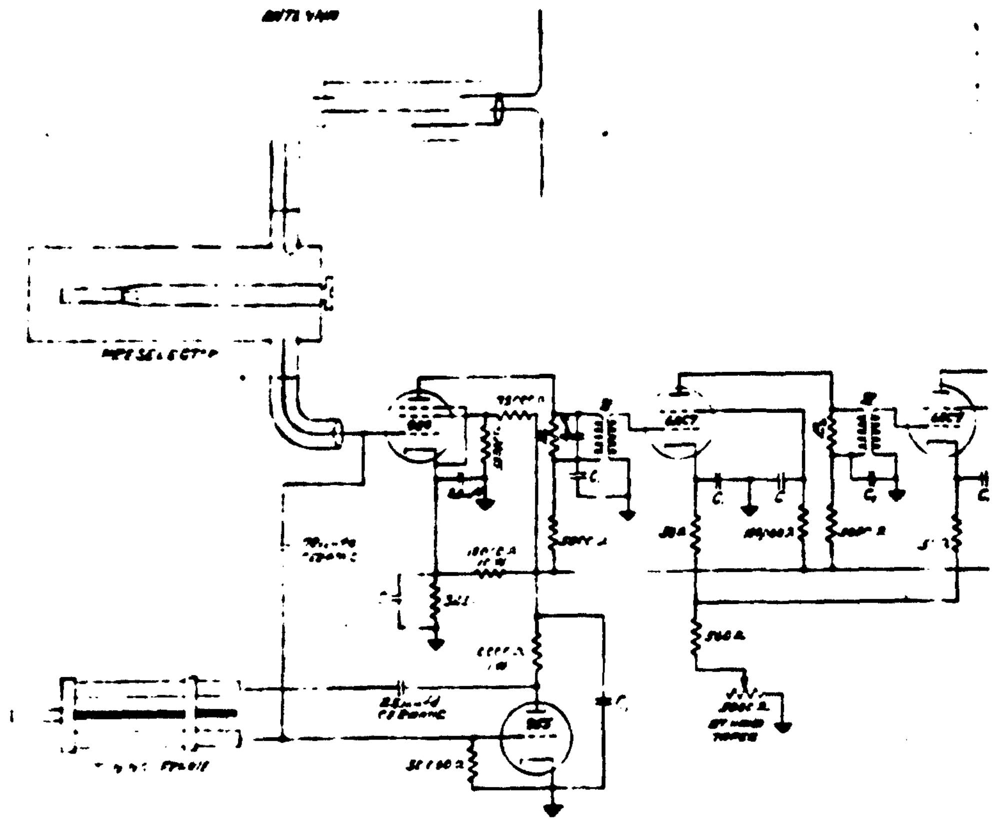
(Refer to Plate 13, Cycle of Operations of Blinker Circuit)

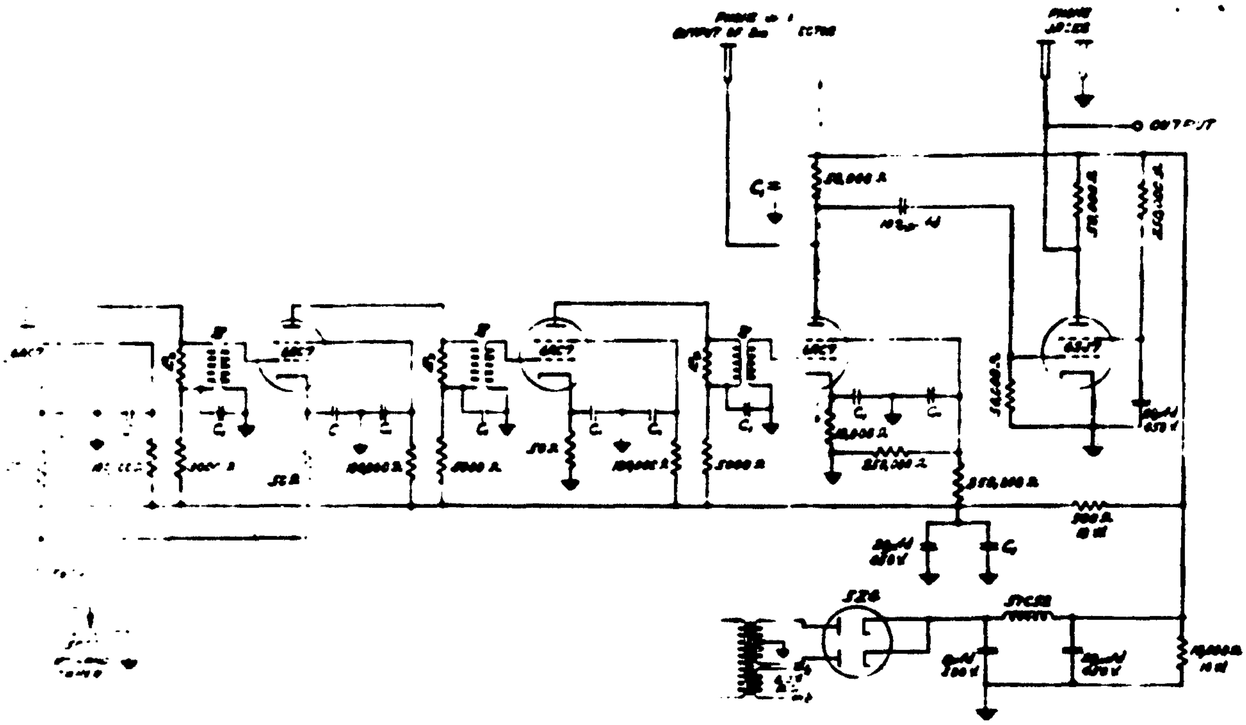
| State | Stage 1 Cond. | Stage 1 Non-Cond. | Stage 2 Cond. | Stage 2 Non-Cond. | $BC_1$ Input | Voltage on Grids of 2050's | Voltage Applied to $PT_2$ |
|---|---|---|---|---|---|---|---|
| 1 | B | A | A | B | | -40 volts | 20 volts |
| 2 | A | B | A | B | Neg. Pulses* | -20 volts | 70 volts |
| 3 | B | A | B | A | Pos. Pulse | -20 volts | 70 volts |
| 4 | A | B | B | A | Neg. Pulse | 0 volts** | 120 volts# |

*$BC_1$ is tripped by the first negative pulse.

**2050's are unblocked and blinker lights.

# $PT_2$ builds up and discharges.



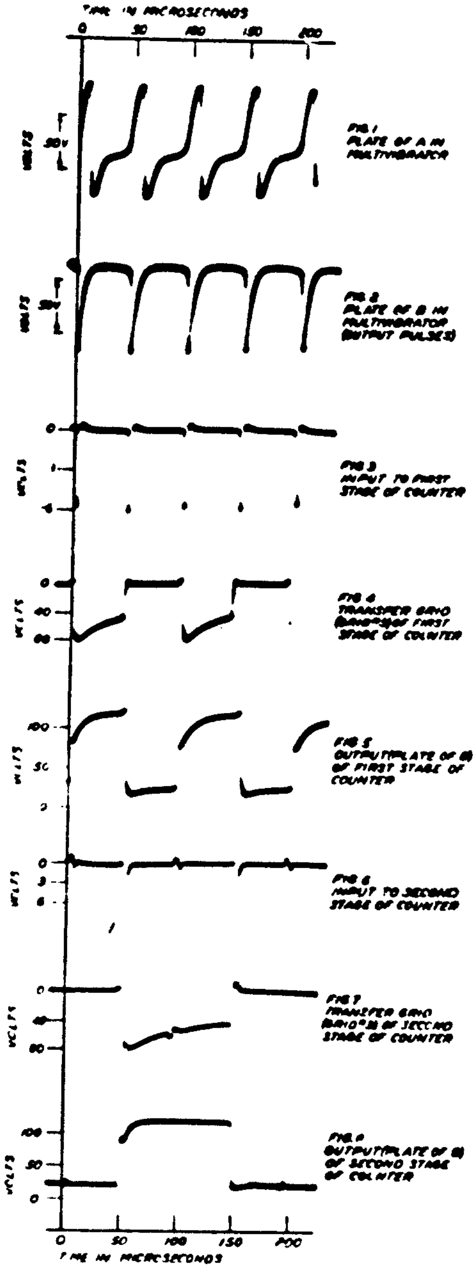



$C_1 = .006\ \mu f$

| | R | [illegible] | $R_1$ | [illegible] |
|---|---|---|---|---|
| RECEIVER #1 | 5000 | 5000 | 5000 | 5000 |
| RECEIVER #2 | 7500 | 5000 | 5000 | 5000 |

CIRCUIT DIAGRAM OF RECEIVER

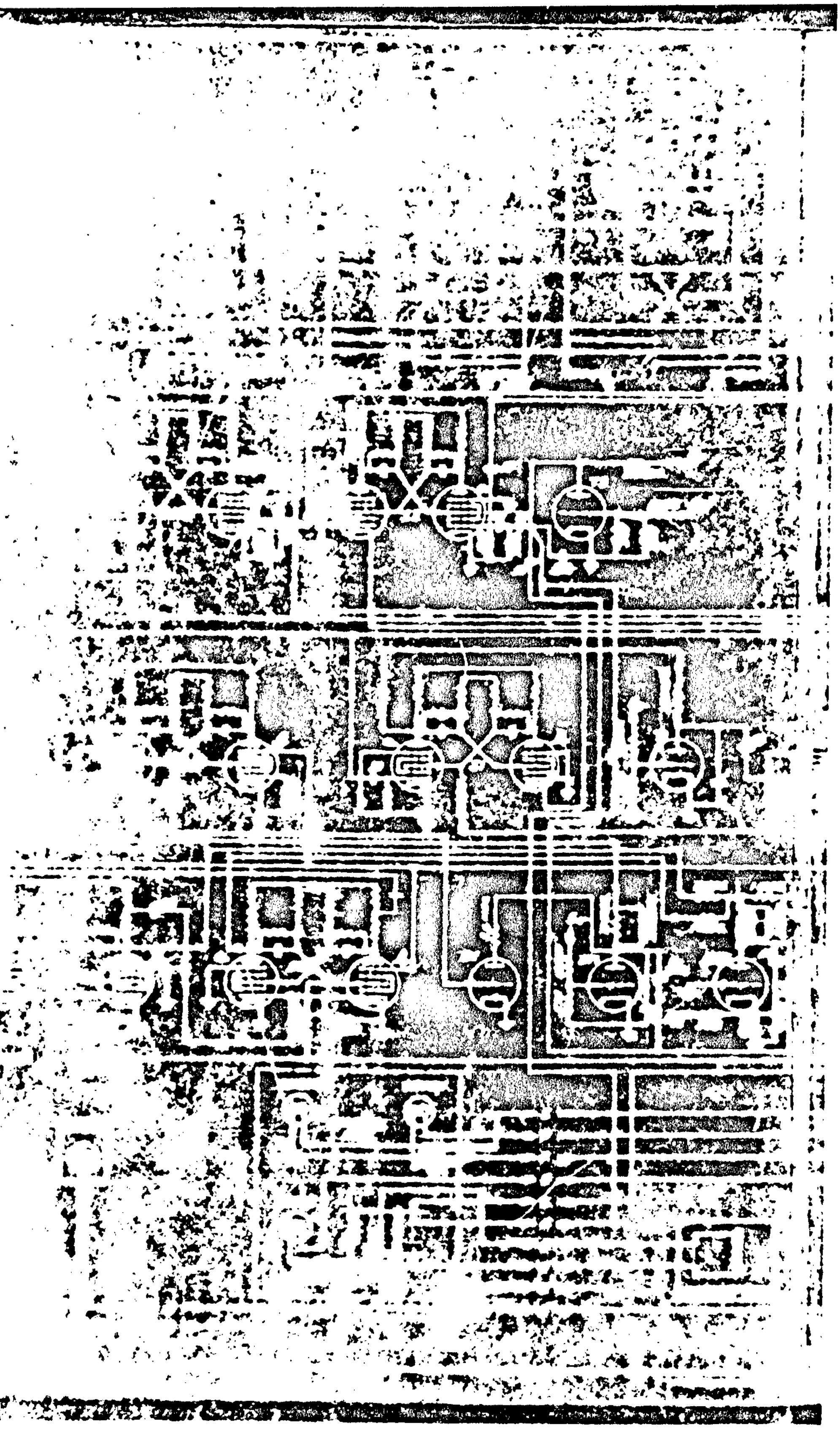
PLATE 5

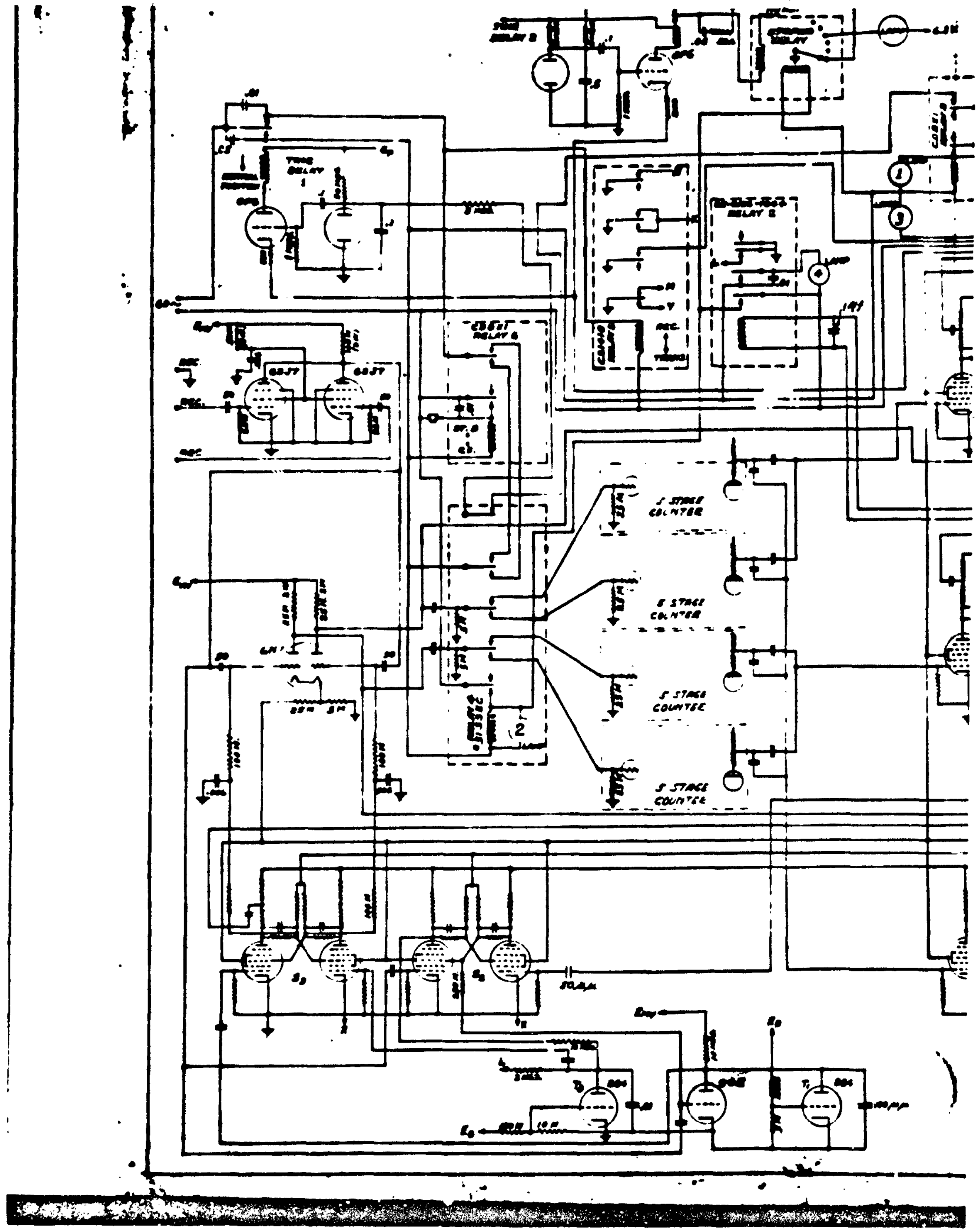



VOLTAGE OSCILLOGRAMS OF MULTIVIBRATOR AND COUNTER

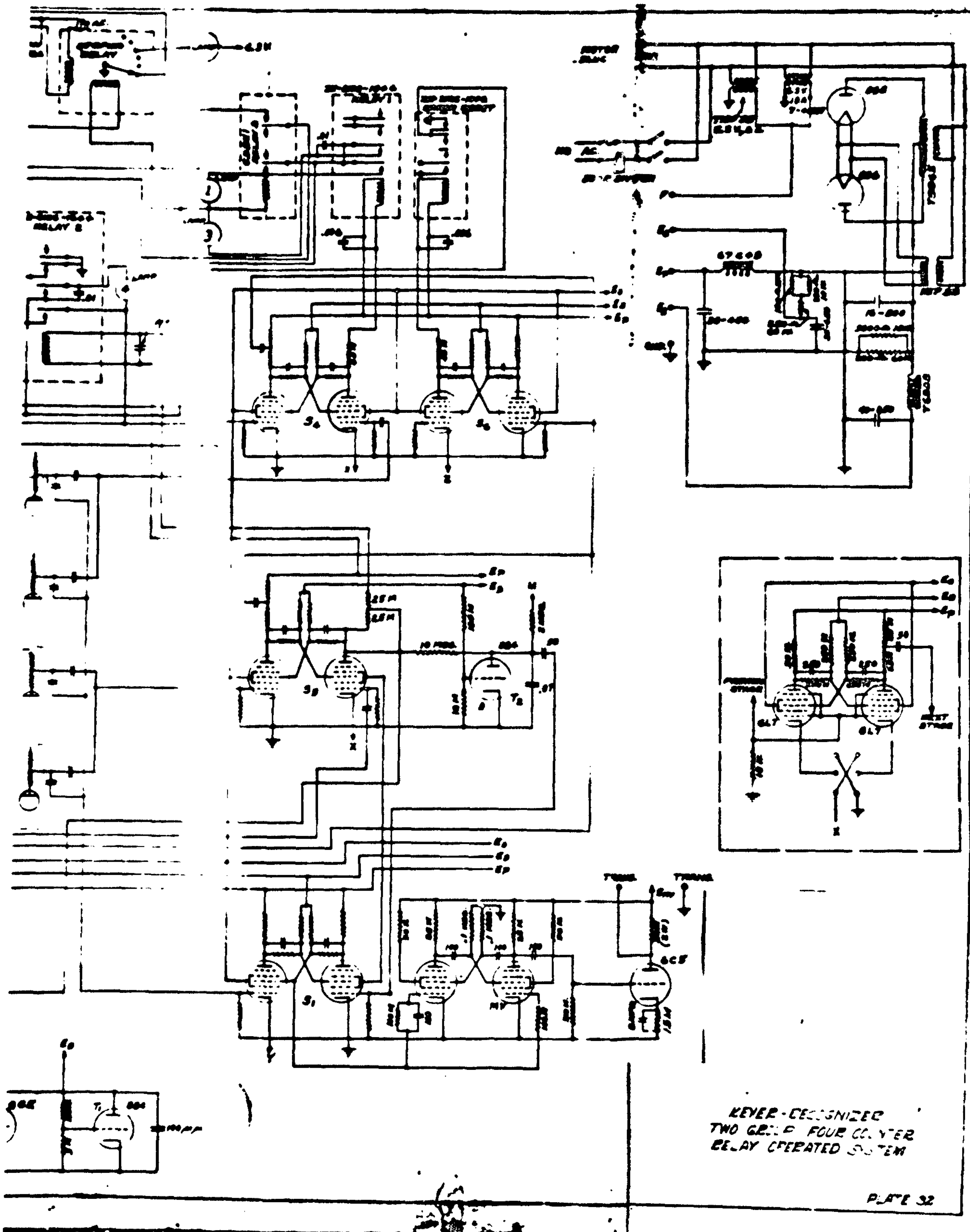
SECRET

PLATE 13



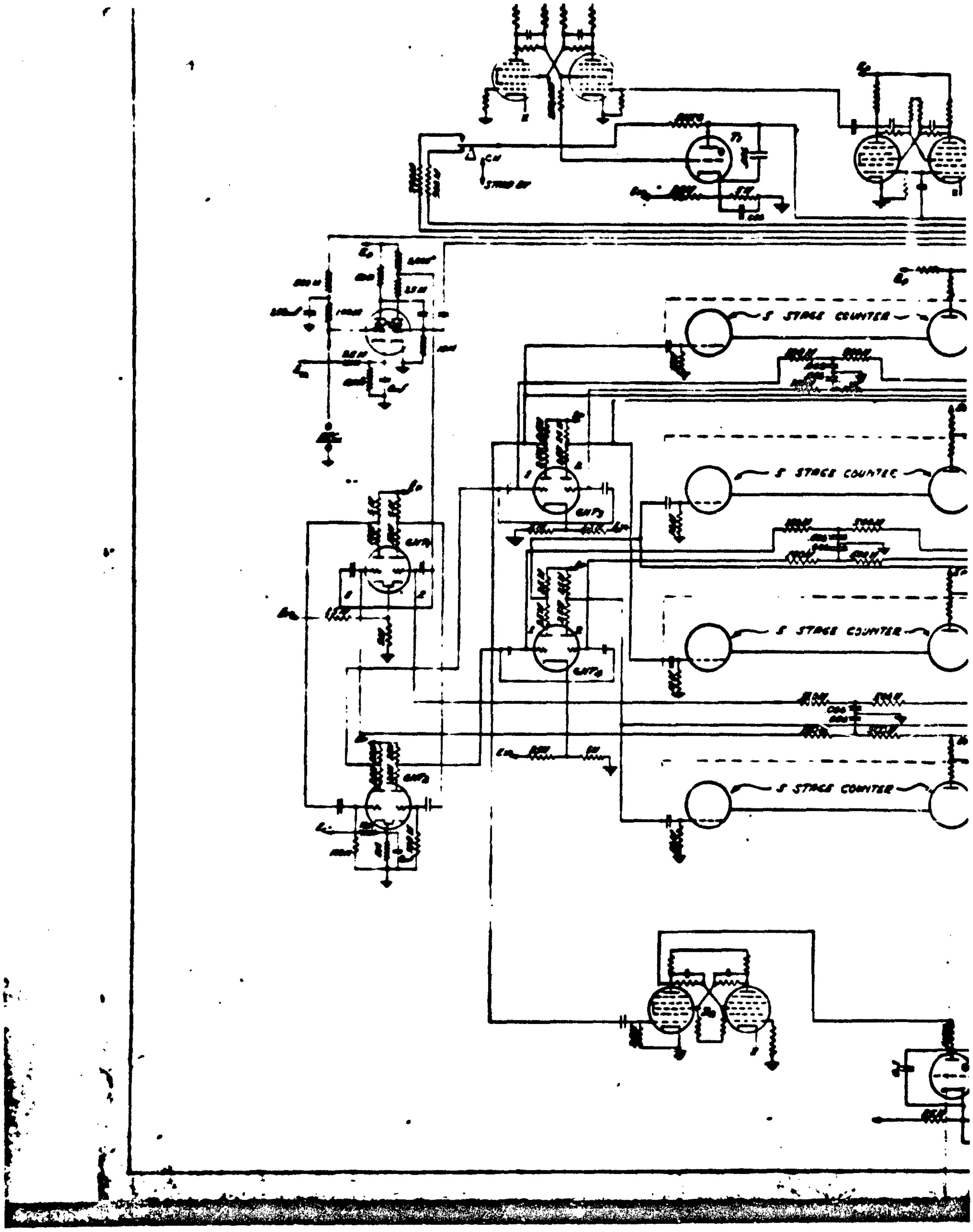


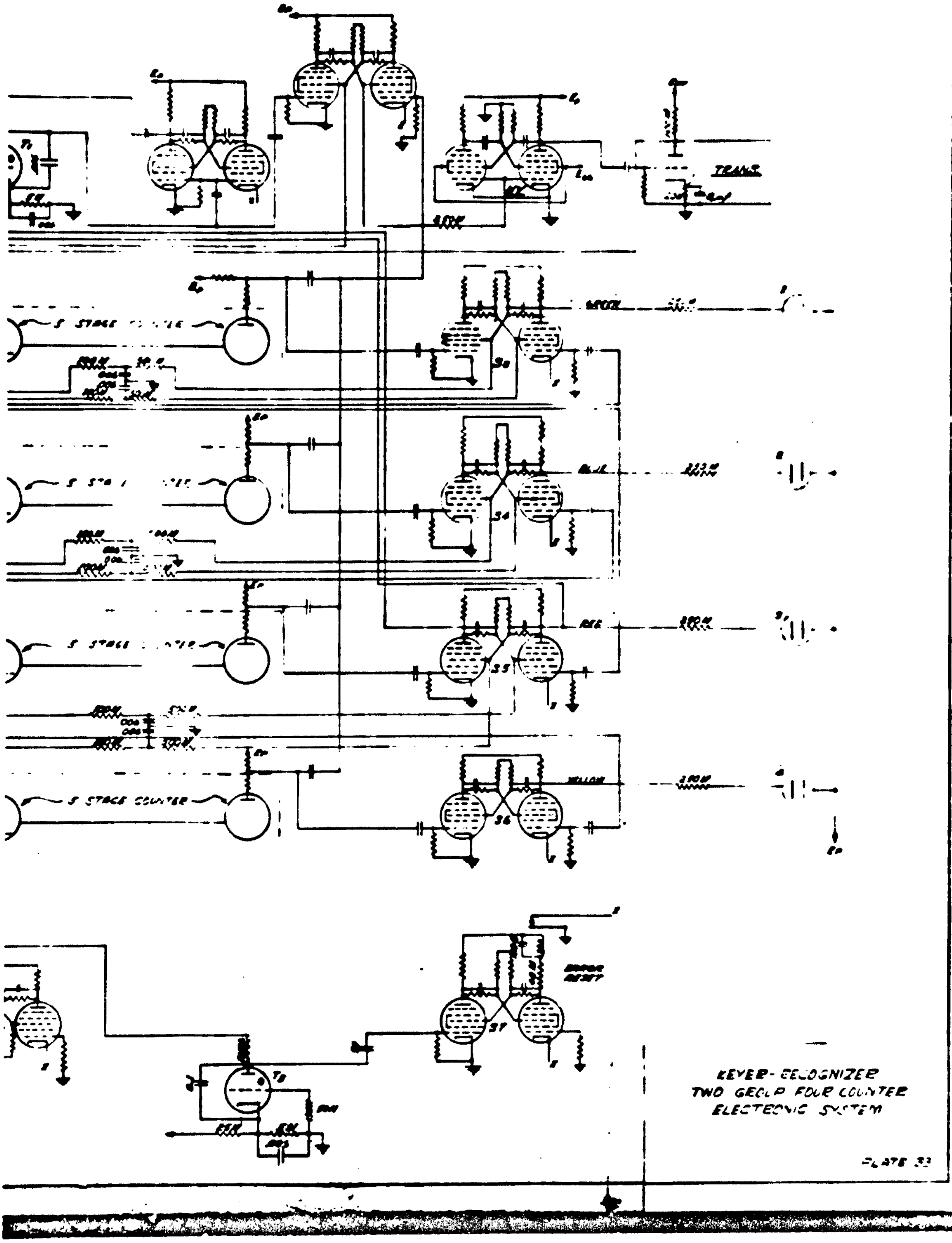
TIME DELAY 1
6SJ7
6SJ7
REC.
5 STAGE COUNTER
5 STAGE COUNTER
5 STAGE COUNTER
5 STAGE COUNTER




KEYER-RECOGNIZER
TWO GROUP FOUR COUNTER
RELAY OPERATED SYSTEM

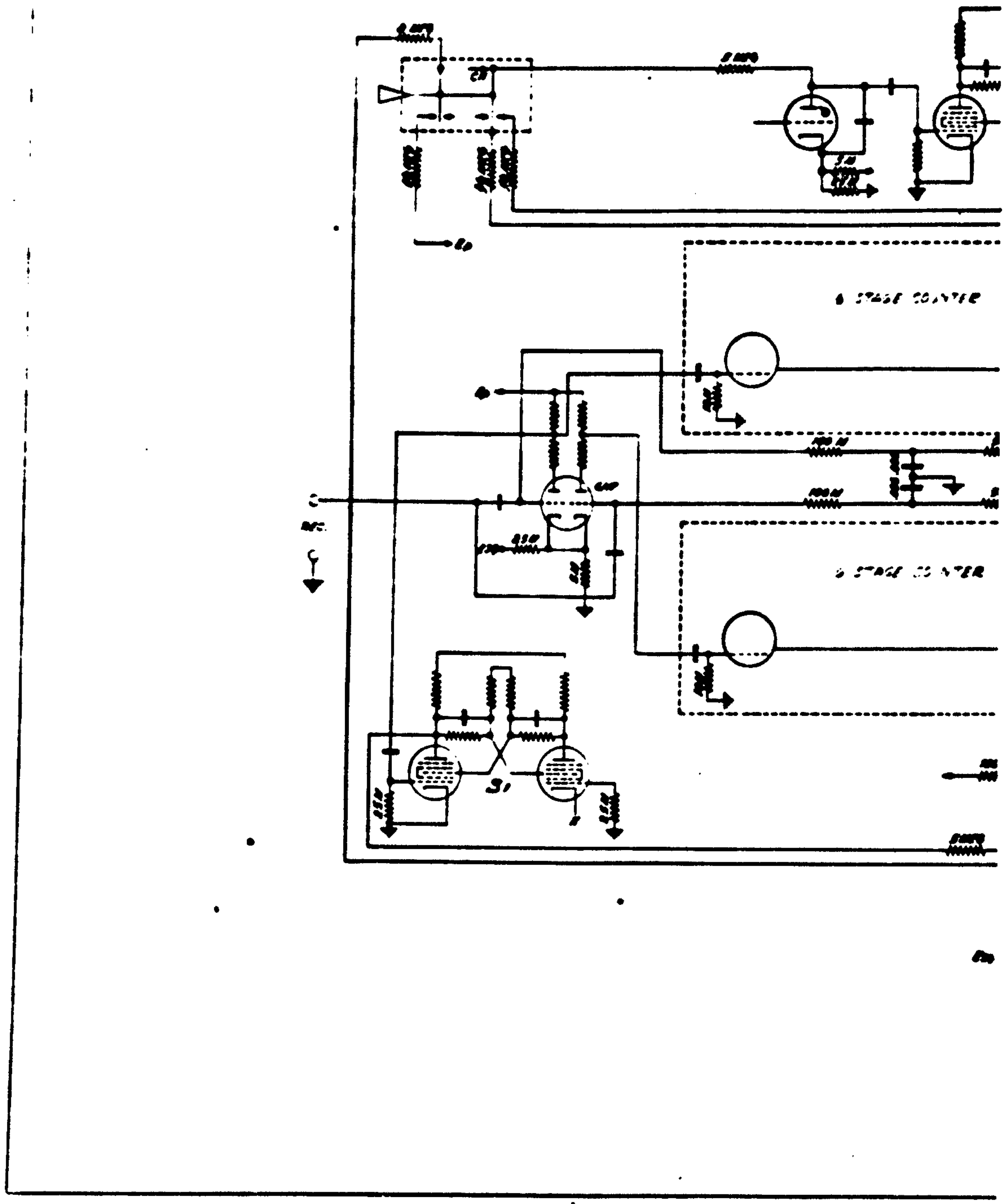
PLATE 32

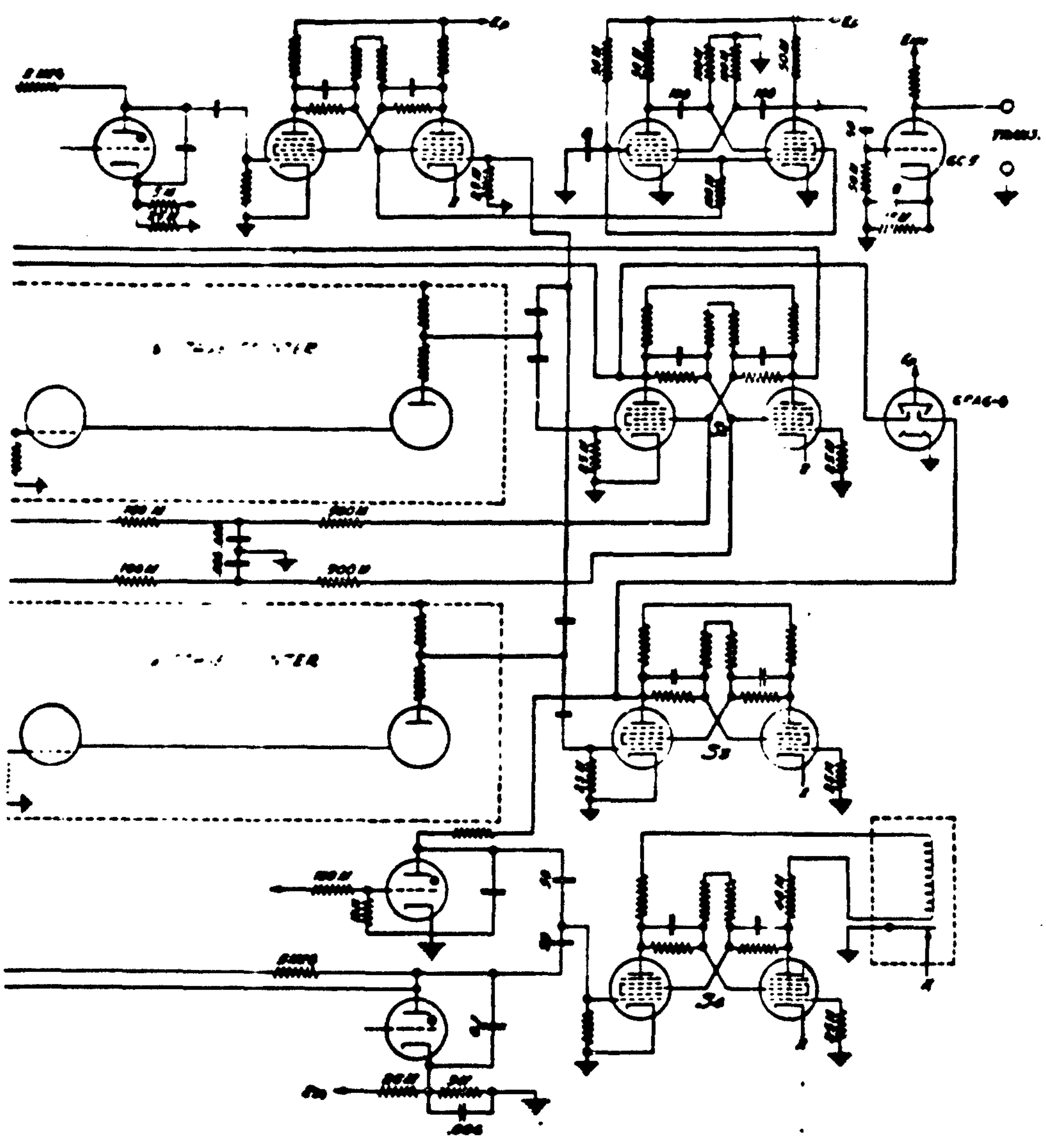

5 STAGE COUNTER
5 STAGE COUNTER
5 STAGE COUNTER
5 STAGE COUNTER




KEYER-RECOGNIZER
TWO GROUP FOUR COUNTER
ELECTRONIC SYSTEM

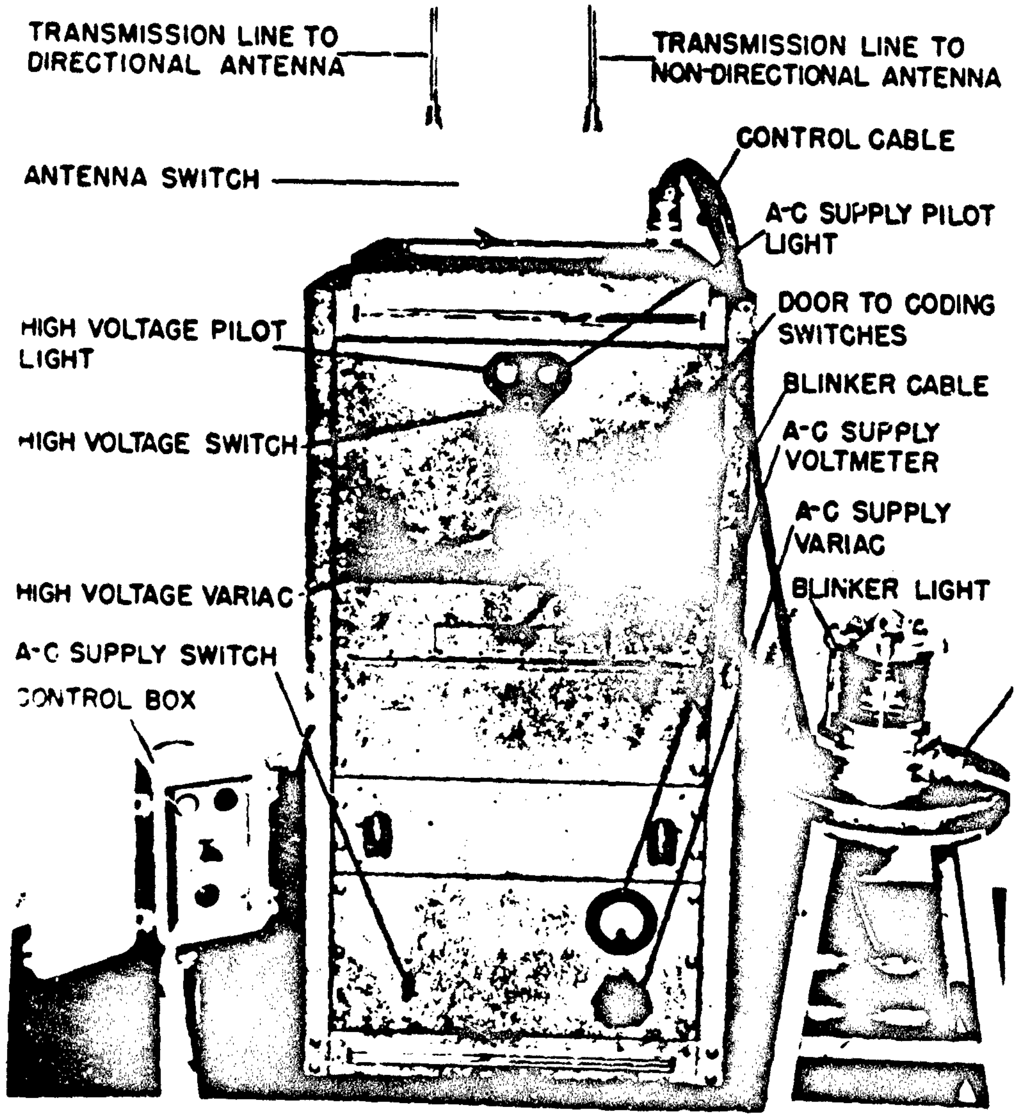
PLATE 33



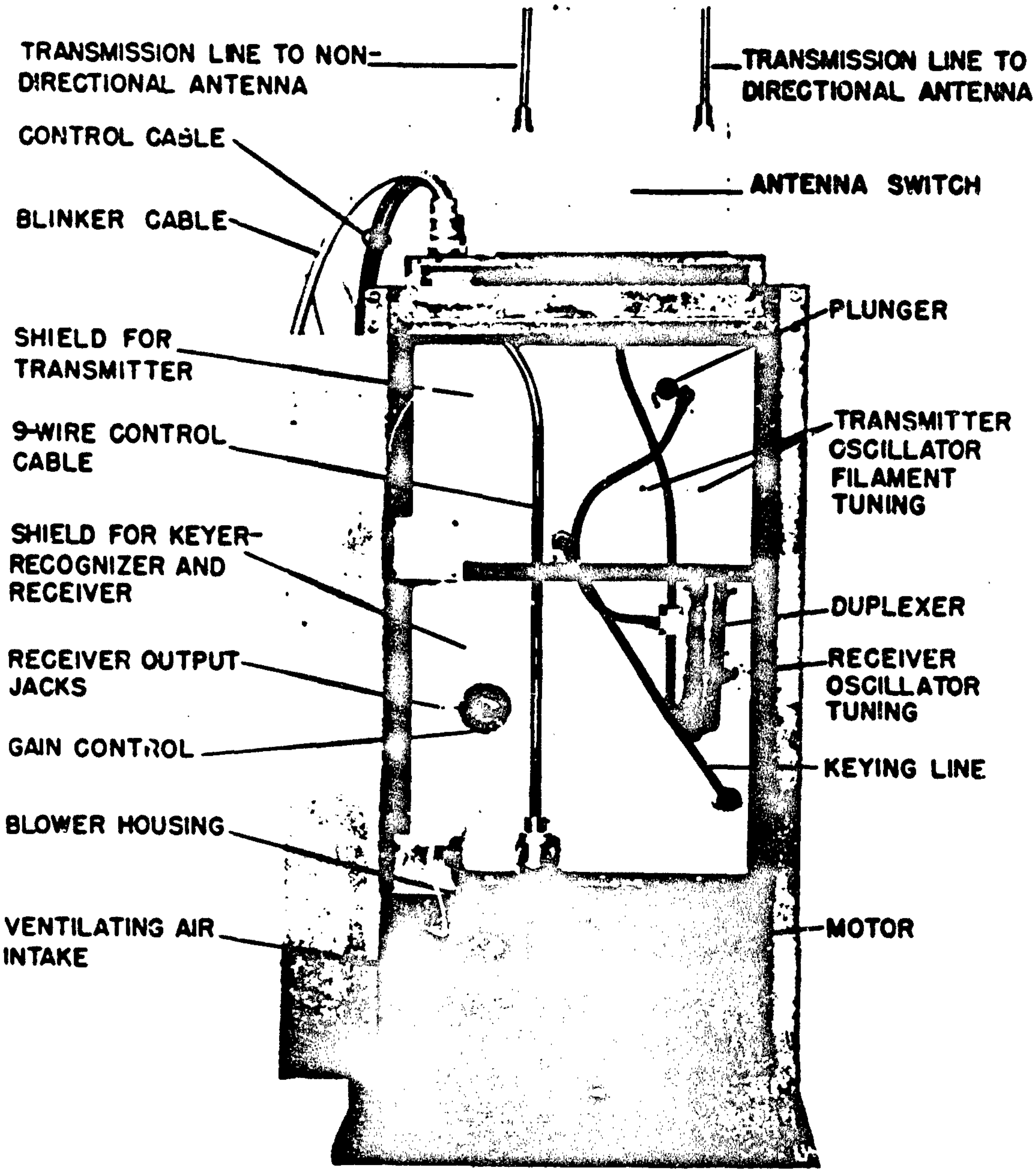


KEYER-RECOGNIZER
ONE GROUP TWO COUNTER
ELECTRONIC SYSTEM

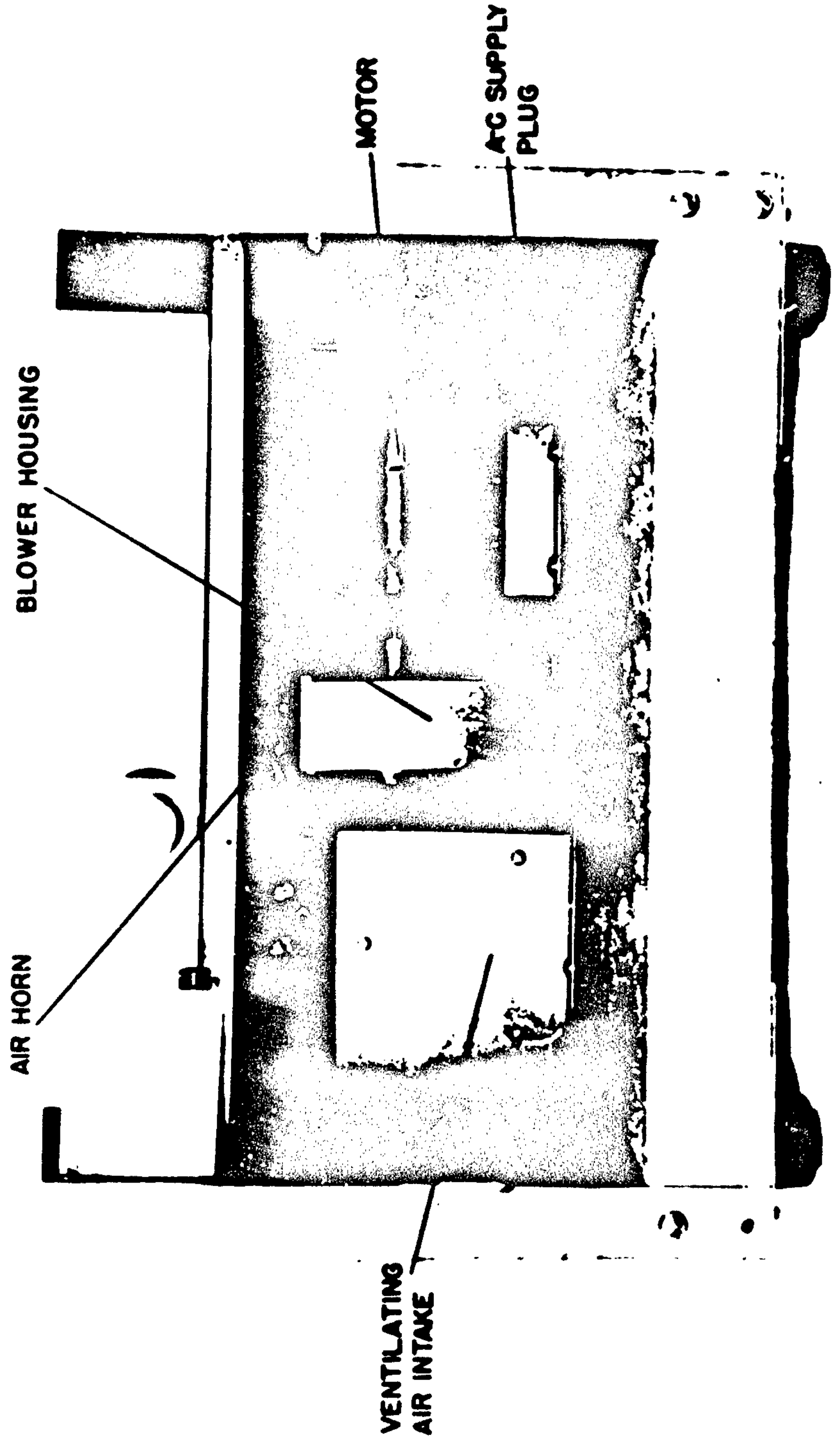
PLATE 34




FRONT VIEW OF UNIT SHOWING CABINET ASSEMBLED, ANTENNA SWITCH, CONTROL BOX, AND BLINKER LIGHT.



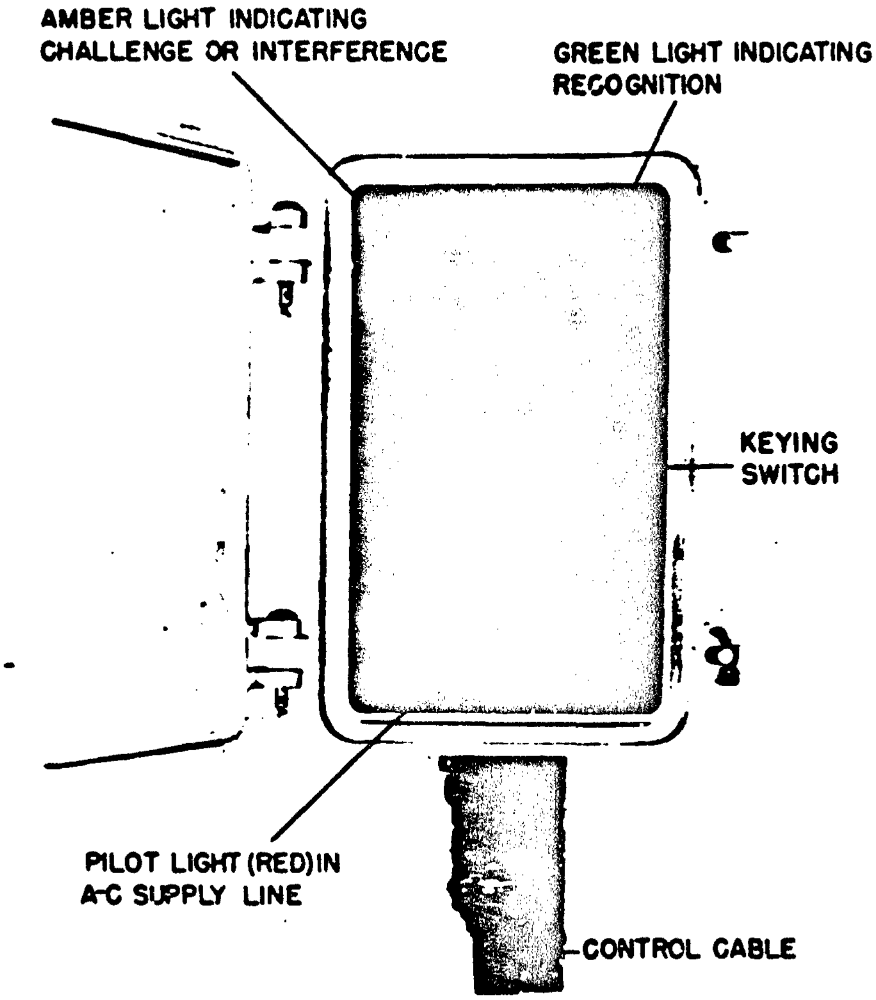

REAR VIEW OF CABINET




REAR VIEW OF CABINET SHOWING BLOWER AND MOTOR

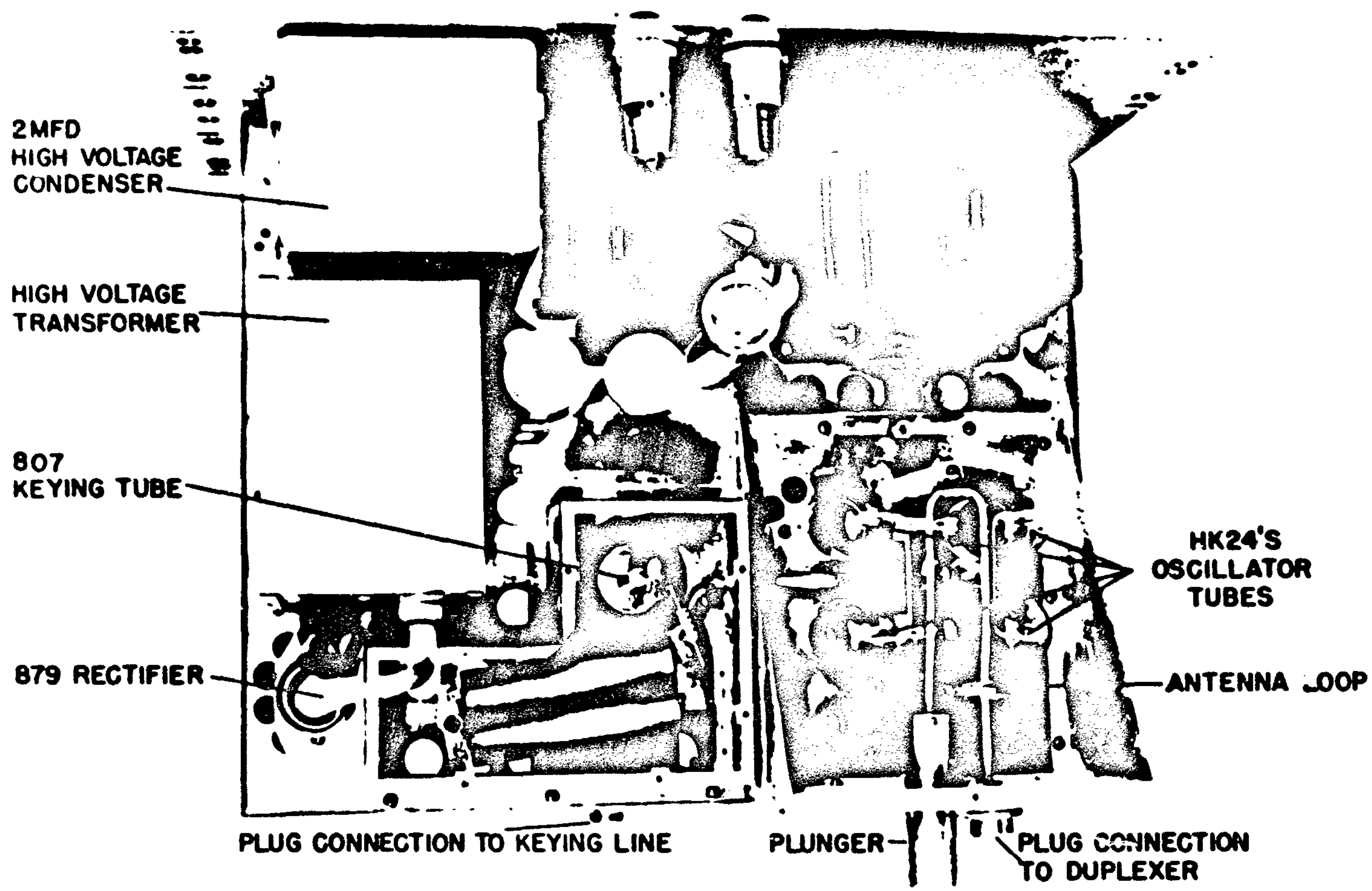
SECRET

PLATE 103

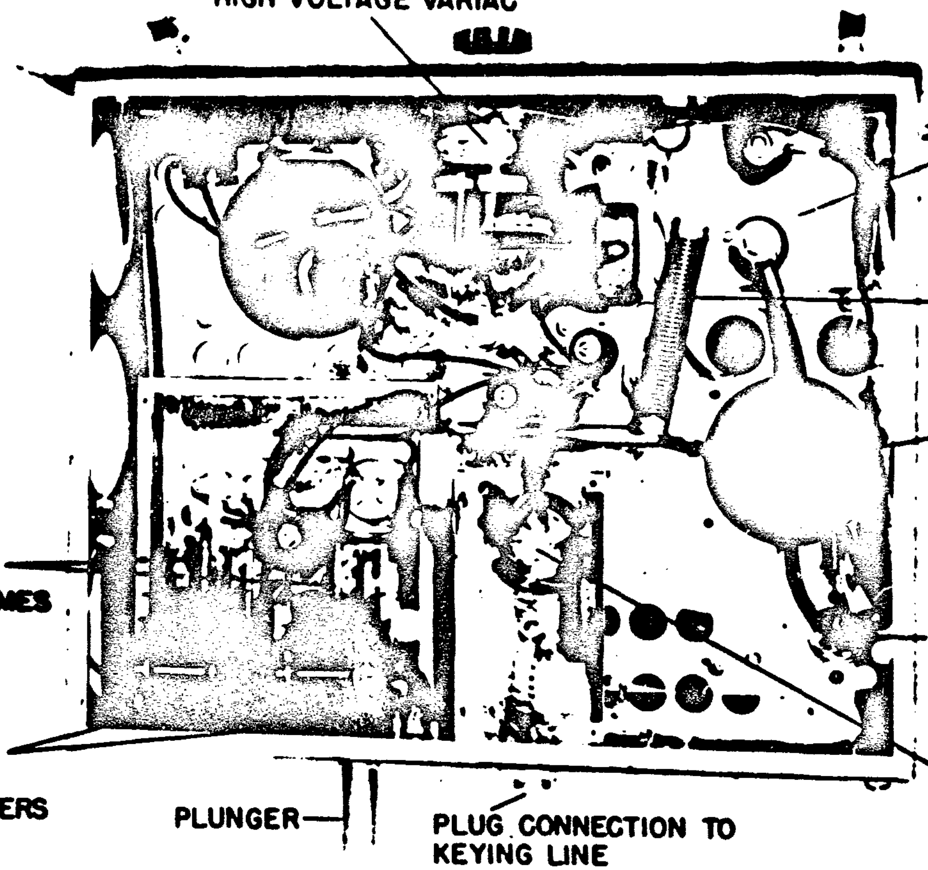



CONTROL BOX

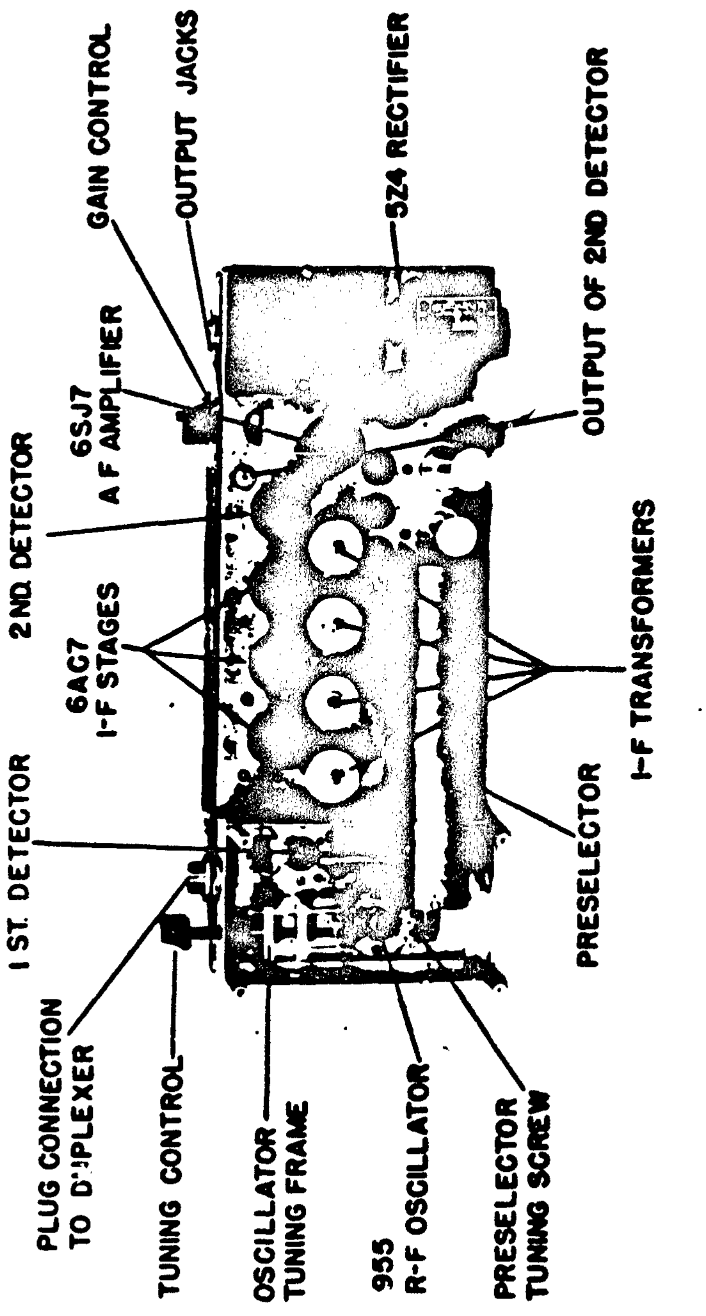
SECRET



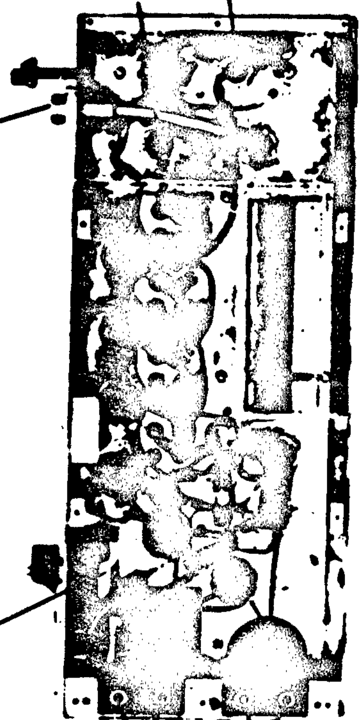

TOP VIEW OF TRANSMITTER



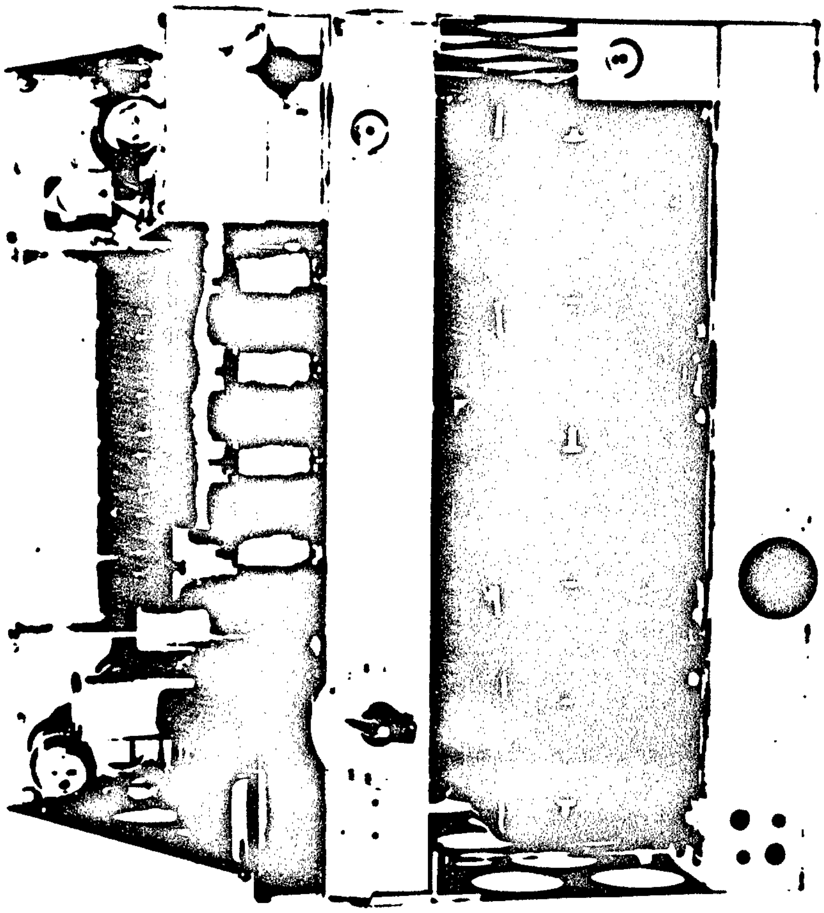

BOTTOM VIEW OF TRANSMITTER



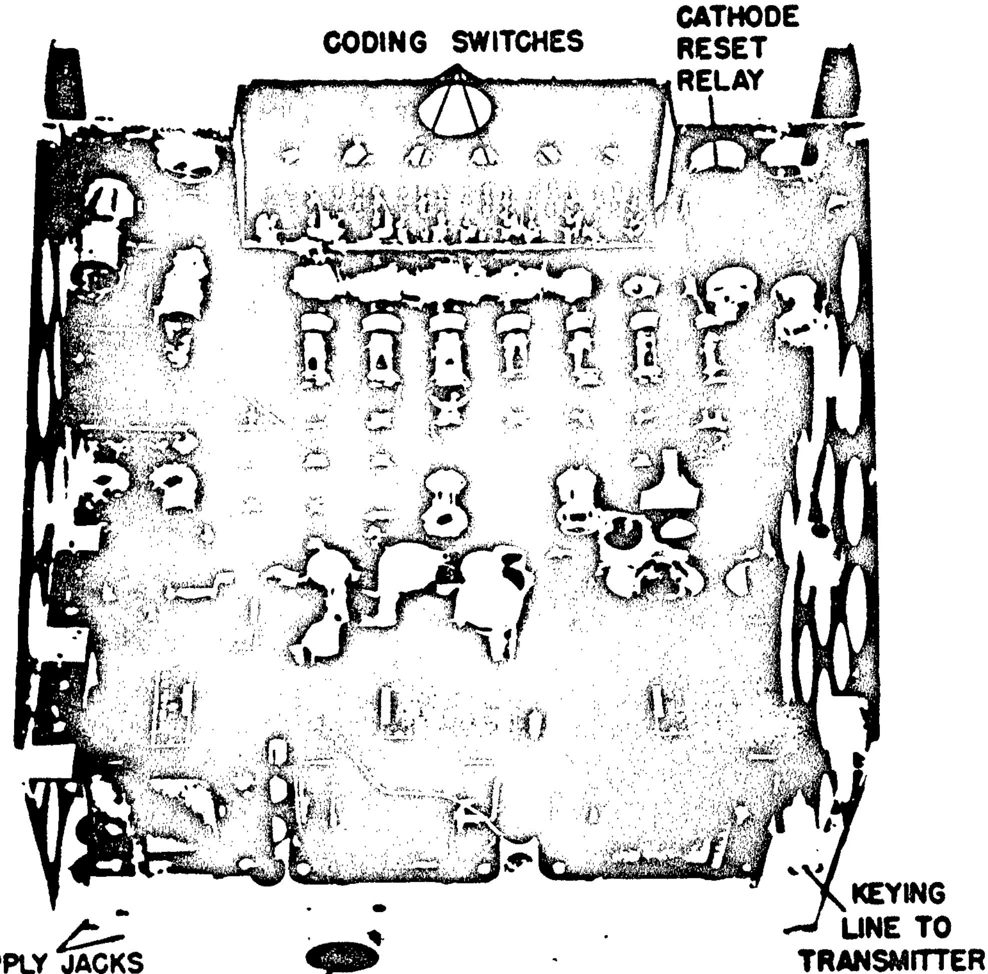

TOP VIEW OF RECEIVER



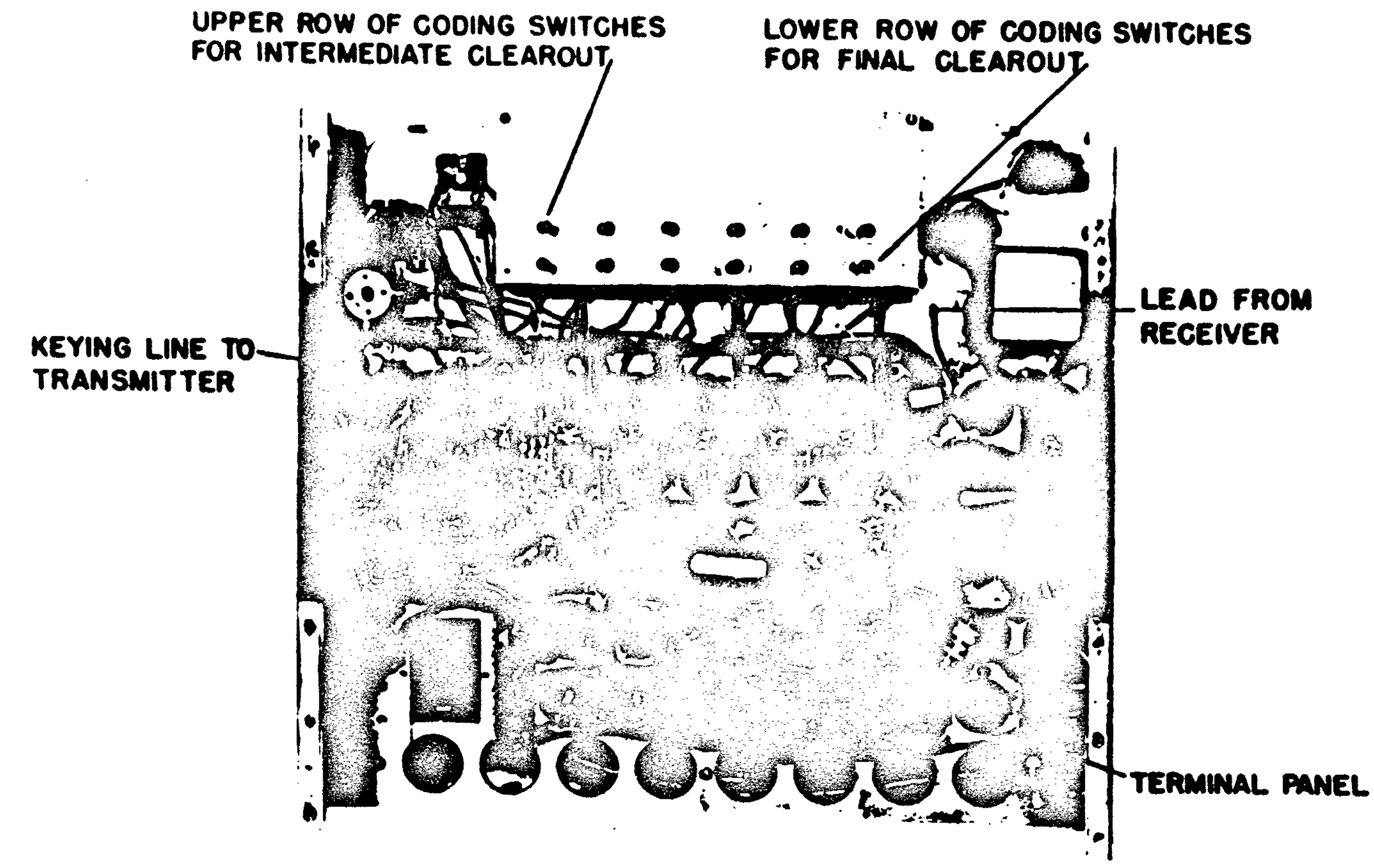

BOTTOM VIEW OF RECEIVER



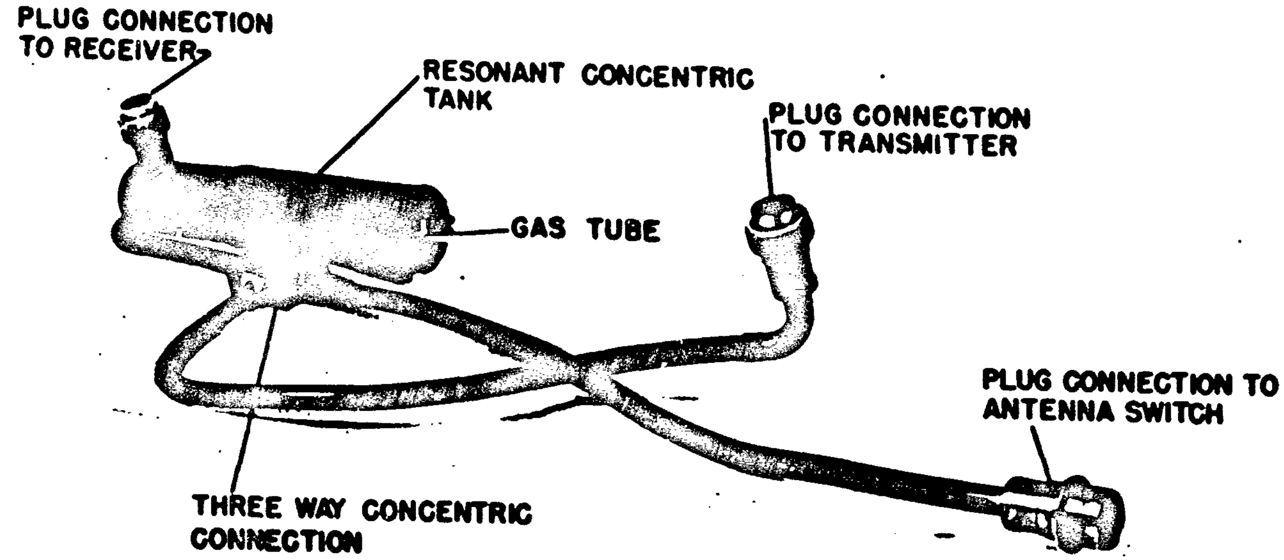
KEYER-RECOGNIZER AND RECEIVER
BACK ELEVATION




KEYER-RECOGNIZER
TOP-REAR VIEW SHOWING COUNTER AND CONTROL TUBES
AND POWER SUPPLY




KEYER-RECOGNIZER
FRONT VIEW SHOWING TUBE BASES OF COUNTER AND CONTROL CIRCUITS




DUPLEXER

PLATE 112

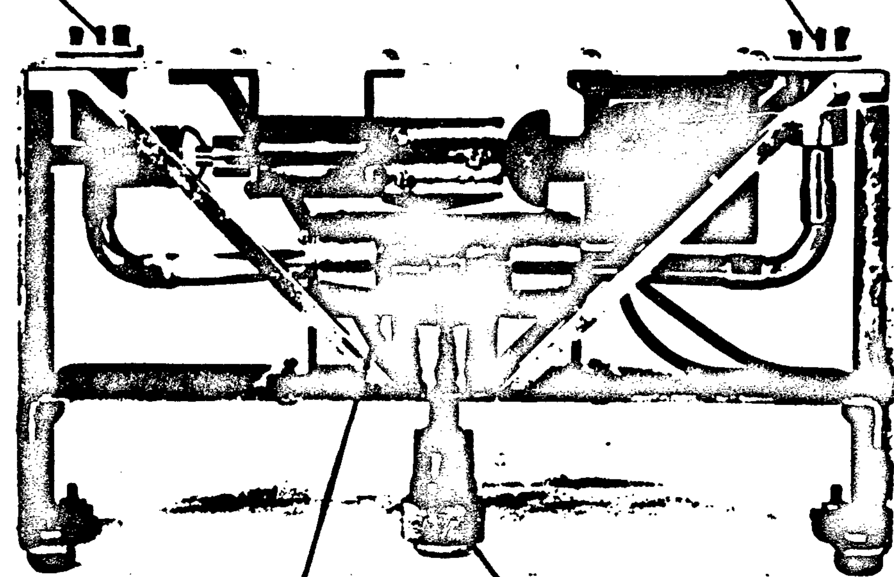
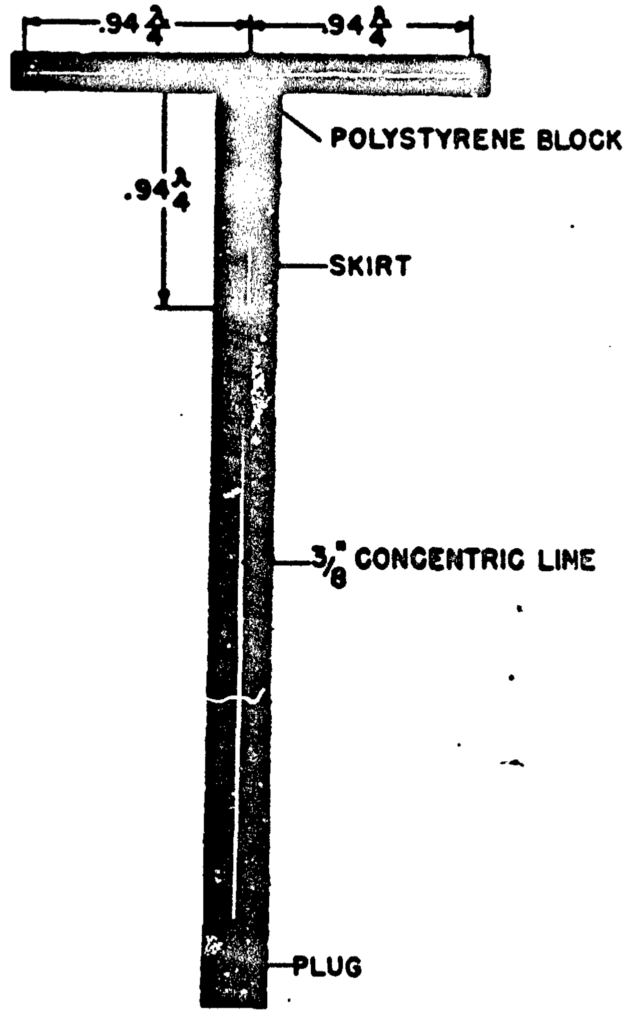


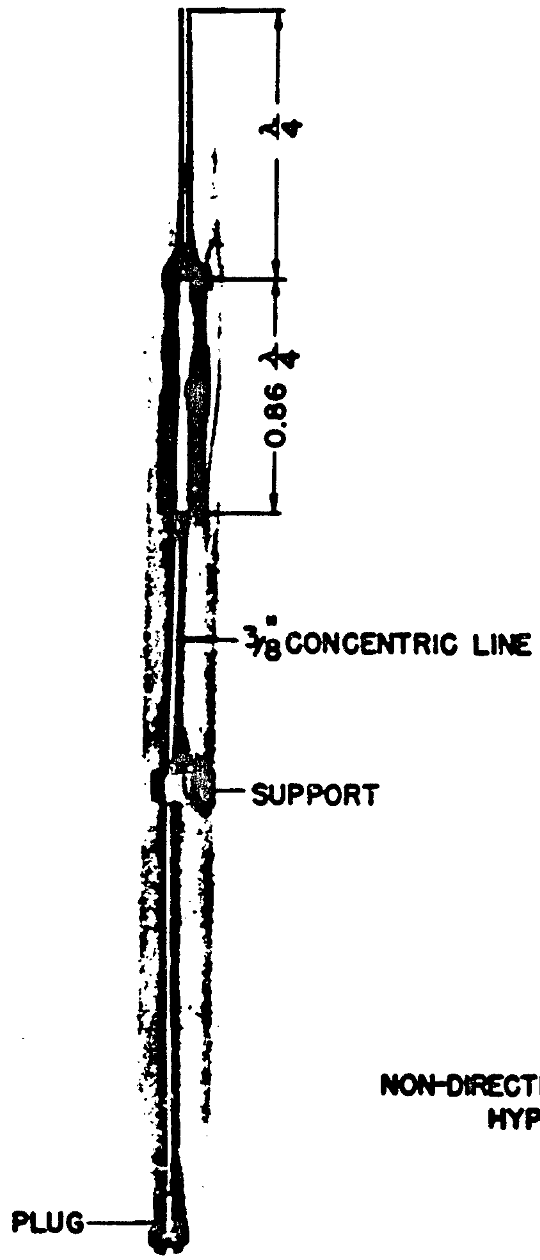

PLATE [redacted]




NON-DIRECTIONAL ANTENNA

SKIRTED DIPOLE

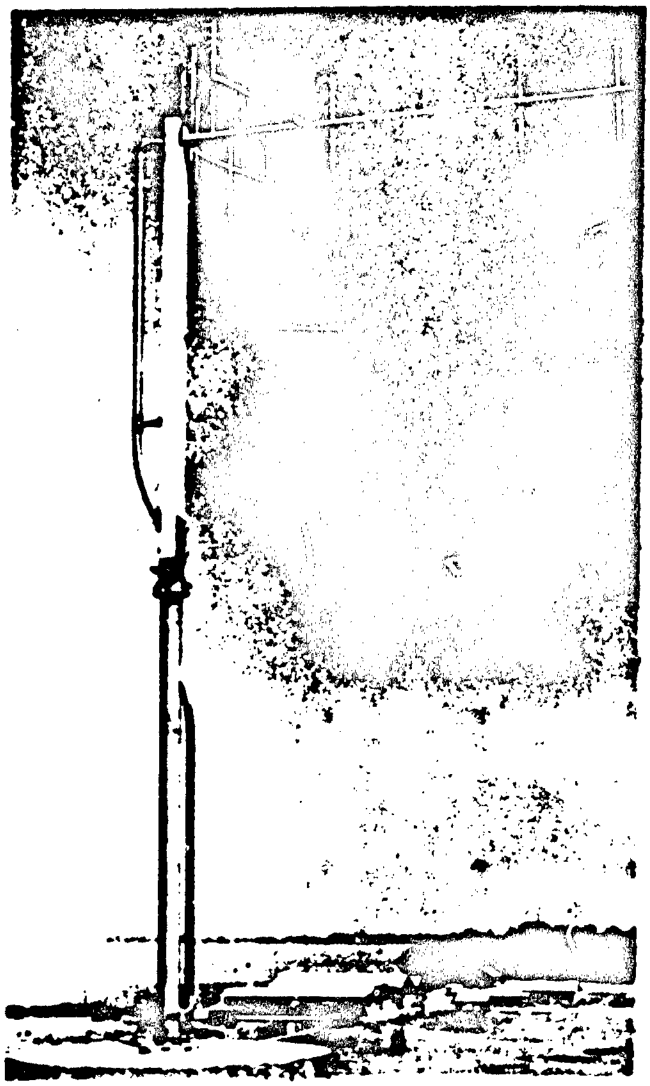
PLATE 114




NON-DIRECTIONAL ANTENNA
HYPODERMIC

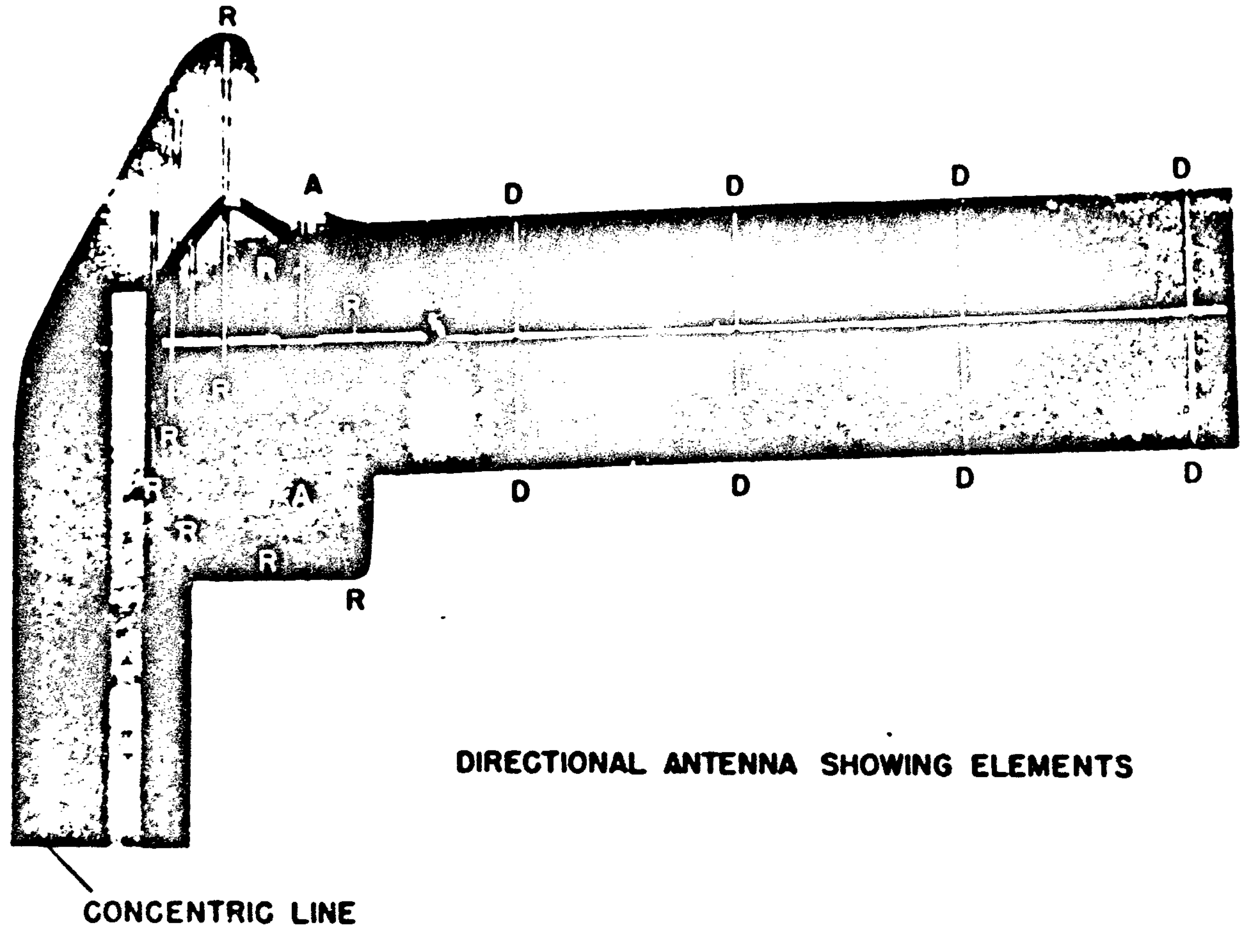
PLATE

[redacted]



DIRECTIONAL ANTENNA INCLUDING SUPPORT AND BASE

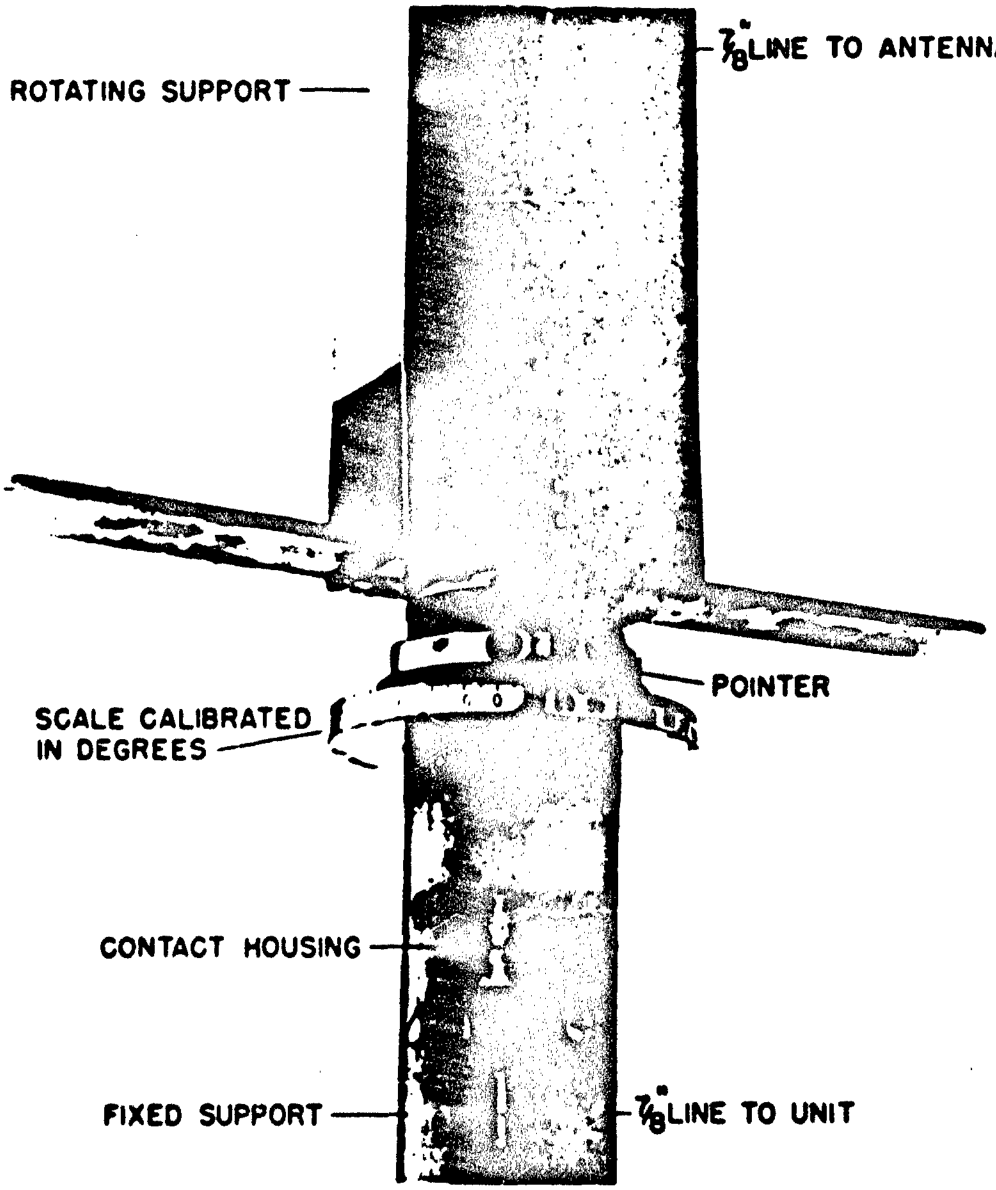
[redacted]




DIRECTIONAL ANTENNA SHOWING ELEMENTS

PLATE 117

[redacted]




DIRECTIONAL ANTENNA SUPPORT SHOWING ROTATING JOINT

[redacted]